MASTER'S THESIS

A Green ICT maturity model for industrial manufacturing

A graduation report into a Green ICT maturity model for the operations phase of physical assets

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Abstract

Industrial manufacturing (e.g. Chemicals or Oil & Gas) is one of the largest consumers of energy and natural resources. Despite mounting pressure from regulators and investors, the development of sustainable practices falls behind. The future is bright however, with new technologies emerging frequently such as digital twins, smart manufacturing, artificial intelligence applications, and many more. When these technologies are applied to consciously improve our environment, this is referred to as Green Information Communication Technology (Green ICT).

Despite projected advantages, the research towards maturity models for sustainability and manufacturing is limited in the context of ICT. The result of literature research and expert knowledge is a Green ICT maturity model for the manufacturing industry, further referred to as GITMM-MANU. The GITMM-MANU is a variation of the SURF model of Hankel from 2017. The developed GITMM-MANU has a specific focus on the operational phase of an asset. The development of the GITMM-MANU follows the principles defined by Design Science Research Methodology (DSRM).

A multiple case study approach in a limited timeframe is used to validate the GITMM-MANU, as well as measure the maturity level for the four participating organizations. The results verified the validity and usability of the GITMM-MANU and provide initial insights of the maturity level. The results provide various recommendations to further improve the GITMM-MANU, as well as suggestions for additional and related research.

Key terms

Green IT, Green IS, Sustainability, Maturity, Model, Manufacturing, Green ICT

Summary

Sustainability is a major topic that is frequently seen in the news. How do we use and preserve our resources for not just our generation to reap the benefits of economic progress, but more importantly, the many future generations after us? In this context, sustainability is mostly thought of as the climate change challenge, however more problems are on our horizon such as e-waste and depletion of natural resource to name two. ICT plays a major part as contributor, but more importantly as solution to the problem. The Global e-Sustainability Initiative report (2015) states that ICT solutions can enable a reduction of CO_{2e} emissions up to 20% globally.

Manufacturing companies are amongst the largest energy consumers. In 2012, the Department of Energy estimated in 2012 that 28% of all the U.S. energy is consumed by industrial manufacturing. Being such a large consumer of scarce resources with abundant opportunities, society recognized this challenge.

Through market pressure, regulations and other means, organizations are forced to report on their sustainability. Global consulting firm KPMG, reports that more and more organizations are actively reporting on their sustainability activities. However, the translation to practical implementations and committing to goals such as the Sustainable Development Goals from the U.N. is lagging, specifically in the U.S. region and industrial manufacturing.

Industrial installations such as for Oil &Gas and chemicals are large, complex, and have a huge impact on the environment, society, and the economy of a region. With a lifespan of several decades and continual changes, a lot of positive and negative impact is possible during the operational phase for an installation. The maturity of how an organization approaches Green ICT during the lifespan of such an installation, has a direct and indirect impact on the sustainability of the organization. The goal of this research is therefore:

Develop a Green ICT maturity model that supports industrial manufacturing organizations in the continual improvement of leveraging ICT to achieve greener operational installations.

There are three concepts central to this research:

The first concept is Green ICT, which is a young and dynamic research field. Academics differentiate between the negative effects because of the use of ICT in terms of energy, scarce resources, e-waste, etc (referred to as Green in IT). Versus the positive effects of using ICT applications, such as global collaboration tools that can prevent travel and thereby lower the carbon footprint (referred to as Green by IT).

The second concept is the maturity model. A maturity model is a proven management instrument to support organizations by providing a method to independently measure the current state and to plot potential future states of the busines. Maturity models have their roots in the early ’90s from the software industry to improve the quality of software. Since then, maturity models have been applied to many different business scenarios.

The third concept is industrial manufacturing. Industrial manufacturing has specific challenges. To ensure that these specific challenges are represented in the developed GITMM-MANU, researcher

utilized an ISO standard (ISO55000) that describes processes for the successful management of a portfolio of industrial installation (assets) across all lifecycle stages.

The literature study revealed that many Green ICT maturity models exist, but few conform to design principles to safeguard the quality of a maturity model. For the development of the GITMM-MANU, two high scoring models were combined and reviewed. To ensure industrial manufacturing was addressed by the GITMM-MANU, specific components were added such as specific process areas for operations, organization, risk, and decision making.

The resulting GITMM-MANU covers four domains:

- Green ICT in the organization.
- Green of ICT.
- Greening of operations with ICT.
- Green ICT in manufacturing.

Across the four domains, 20 attributes (e.g. Work Practices Management) are used to categorize a total of 122 components. Each component is provided with a short question to clarify and support the respondent in rating the component on a scale from zero (low maturity) to five.

The empirical phase of the research was focused on testing the developed GITMM-MANU for validity and output. Validation took place in the form of a case study amongst large industrial manufacturing companies. Four industry experts have participated, completed the proposed GITMM-MANU, and participated in the semi-structured interviews.

The results have been analysed using thematic analysis. This approach provided the necessary insights to answer the research questions and proposals to improve the GITMM-MANU. In addition, new themes have emerged and proposed as additional research topics. Building on the work of Hankel, the factors of influence are used to extract additional details from the data, providing more insights in the results.

The results of the empirical research are that the GITMM-MANU is a high-quality first version to measure Green ICT in an industrial setting. Based on the research outcome, the GITMM-MANU can be used to develop a high-level roadmap, but specific industry specialists will be required to implement specific areas of the roadmap.

The participating organizations completed the developed Green ICT assessment. Green ICT was a new concept for the participating organizations, which is reflected in the low score of “initial” across the participating organizations.

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1. Introduction

This report is the conclusion of a master's graduation assignment, with the goal of developing a maturity model for Green ICT and industrial manufacturing. The approach used in this report follows a research procedure as provided by the OU (Open University) and is aligned with DSRM (Design Science Research Method) for developing information system models. Researcher lives in the United States (U.S.), which is why the focus is on U.S. based organizations.

1.1. Background

Almost every day there is a new article that breaks a previous prediction in terms of global emissions, rising temperature, the rise of seawater, bleaching of corals, extinction of species, severe storms, long periods of drought, plastic pollution and many more. Even what was previously thought of as pristine remote areas are polluted with airborne plastic waste (Green, 2019). Humanity's climate problems are real and complex. Scientists worldwide agree that beyond a certain point of curbing our CO_2-emissions, we will see a catastrophic change in our climate with predictions running from a few years out to 2045 at best (Aengenheyster et al., 2018).

In the above context, industrial manufacturing is a large consumer of resources in the U.S. According to research performed by the U.S. Department of Energy's Energy Information Administration (EIA), industrial manufacturing consumes 28% of all energy used by the U.S. (S. Brueske, R. Sabouni, C. Zach, H. Andres, 2012). The amount of energy consumed is an important component; it is however not the only consideration for sustainability. Sustainability is a long-term process to optimize economic, environmental, and social performance. Curbing CO_2 emissions, preventing resource depletion, waste prevention, and at the same time providing economic benefits are all part of this complex puzzle (Loeser, 2013).

The good news is that regulators, stock exchanges, and investors are playing an active role. They are mandating corporations to report on Corporate Responsibility (CR) as part of their financial disclosures (Blasco & King, 2017). In addition, the United Nations (U.N.) has introduced seventeen Sustainable Development Goals (SDG) to be achieved by 2030 that combined will contribute to a more sustainable future (United Nations, 2015). CR Reporting and SDG's provide a framework for organizations to define their sustainability agenda. Specifically, SDG's help companies to transform from reporting on things they do (CR), to measurable achievements (Schönherr et al., 2017).

Consulting firm KPMG describes that CR reporting is steadily rising but linking the CR reporting to actual SDGs is lagging across all sectors and regions. KPMG interviewed the 250 largest companies globally and concluded that the U.S. region is the worst performer. Specifically in an industrial manufacturing setting (e.g. Chemicals and Oil & Gas), linking SDGs is more of an exception than a rule (Blasco & King, 2017).

To exemplify this, Arcadis – a global engineering service provider – has performed research towards capital planning and delivery strategies for the manufacturing industry. The Arcadis report concluded that only 58% of the respondents in the manufacturing industry considered sustainability as significant in their approach to capital expenditures (Meer et al., 2017). With the KPMG report in mind, these numbers are no big surprise as the KPMG report displays a similar picture that describes manufacturing as poor performers for translating corporate responsibility to sustainable goals (Blasco & King, 2017).

The ICT industry is seen as an important part of the sustainability puzzle. It is both a contributor to the problem, as well as a solution provider. A report from the Global e-Sustainability Initiative found that ICT, when referred to as the lifecycle of hardware and its associated use of resources will contribute about 1.97% of the global CO_{2e} emissions by 2030. This is in contrast to a potential reduction of up to 20% in global CO_{2e} emissions by 2030 through the application of existing and new ICT applications (Global e-Sustainability Initiative, 2015, p. 8).

With this large discrepancy between the potential for ICT applications and the lack of commitment from industrial manufacturing, it seems common sense to drive the Green ICT agenda for manufacturing. Maturity models in this context are recognized as useful management instruments for measuring current status and roadmap development (Becker et al., 2009). This report will provide insight into the application of Green ICT maturity models with a focus on industrial manufacturing.

1.2. Exploration of the topic

This report is organized around the scientific field of maturity models with a specific focus on Green ICT for industrial manufacturing. This chapter will explore Green ICT and maturity models, before developing a theoretical framework in chapter 3.

1.2.1. Green ICT

The scientific field for Green ICT is young, and researchers have struggled with a definition of what Green ICT is. Loeser conducted an extensive literature review for composing a clear definition of Green IT. Where Green Information Technology (IT) refers to measures and initiatives to decrease the negative environmental impact of the operations of IT technology and infrastructure. Green Information Systems (IS), on the other hand, is considered a broader concept and refers to practices for the use, deployment, investment, and management of IS to minimize negative environmental impacts (Loeser, 2013). The negative impacts of IT should not be underestimated. In the year 2016, tens of millions of tonnes of electronics were sold, and equally generating millions of tonnes (44.7) of e-waste (Balde et al., 2017). In the vision of Loesser, Green IT is a component of the wider Green IS definition. Other researchers have taken a similar approach in describing Green IT/IS efforts that are not as harmful as part of the whole-of-life lifecycle for both equipment and IS systems (Elliot, 2007). Erdélyi also clearly distinguishes between the application of IT versus the physical things that define IT and have an impact on the environment (Erdélyi, 2013):

> **Green by IT**: in which IT is understood as an enabler, providing the tools needed to allow tasks of diverse nature in diverse areas to be carried out in a way that is sustainable for the environment.
>
> **Green in IT**: in which IT is understood as a producer; that is, where IT itself has an impact on the environment due to energy consumption and the emissions it produces, this impact must, therefore, be reduced.

We can imply from the different recent definitions, that the field is still developing. However, most definitions acknowledge the difference between the physical impact of the IT component versus the use and application of IT. The definitions of IT, IS, and ICT are related and sometimes used interchangeably. In this report it will therefore be referred to as ICT. With a better understanding of what Green ICT is, the question arises on how to advance an organization on the topic of Green ICT.

1.2.2. Maturity models

At present, it is close to impossible to look at any business process that is not dependent on ICT in some shape or form. To what extent this process is optimized and aligned with the strategic goals is a different question and relies on a continual improvement process and assessment of the current position against internal and external goals, laws, requirements, etc. (Becker et al., 2009).

As business leaders seek these improvements, they need management instruments and methods to drive their agenda. This is where maturity models come into play, by using the model for evaluation of the current state as well as providing direction for improvements (de Bruin et al., 2005). For a given business area (e.g. ICT or finance), a maturity model allows an organization to measure itself against a given set of criteria.

Depending on the design of the model, the measurement either takes the form of level descriptions, where each level provides an established list of criteria to achieve the level. Alternatively, measurements can be taken based on a Likert scale approach where a detailed question will guide the respondent in answering on a pre-defined scale. In both cases, the lower score represents an area that is less developed, where the higher scores represent well developed or optimized areas. The scoring then presents a potential roadmap for a given domain as it progresses to higher levels on the scale.

ICT Maturity models found their origins from the need to better manage software processes, during the late ’80s and 90’s when many ICT projects were over budget and excessively late whilst often not delivering what was promised. The Software Engineering Institute with support from Mitre Corp. developed a first process maturity model which later evolved into the Capability Maturity Model or CMM (Paulk et al., 1993).

1.2.3. Deliver greater value from Green ICT

To understand the balancing act between delivering ICT value and sustainability, the Innovation Value Institute has developed the IT-CMF framework to provide corporations a management tool to deliver greater ICT value whilst doing this in a sustainable manner (Donnellan et al., 2011). Driving shareholder value, whilst balancing environmental and social dimensions (also called People, Planet Profit) is an area that was first researched by John Elkington in the mid-’90s (Elkington as cited in Slaper, 2011). His effort was focused on providing a more comprehensive view of a business and is since then widely used as a basis for CR reporting also known as the triple bottom line (Slaper, 2011). Recent studies have also shown that firms with a higher commitment towards sustainability (e.g. Green ICT) have weathered the financial crisis (2008, 2009) much better than their peers. The financial performance exceeded those that showed less commitment (Amiraslani et al., 2018).

1.3. Problem statement

The introduction described industrial manufacturing as both one of the largest contributors in terms of pollution and at the same time having many opportunities for improvement. During the lifespan of these industrial installations (assets), many projects are executed to extend the physical,

economic, and competitive lifespan where sustainability has the potential for consideration. Many external forces such as regulators, investors, and the social climate are forcing companies to become more sustainable. However, the actual implementation of sustainable (ICT) practices seems to be lagging for industrial manufacturing. The researcher, therefore, summarizes the problem as follows.

Sustainability and Green ICT seem to be an underdeveloped area for industrial manufacturing. With an apparent lack of a Green ICT maturity model, companies are struggling to articulate their current and future state to achieve a higher level of Green ICT sustainability.

This report will develop a Green ICT maturity model (GITMM-MANU) to measure the positive and negative effects of ICT on the environment with a specific focus on industrial manufacturing and the operational phase of an installation. The goal is to provide a management instrument that allows organizations to better articulate strategies to optimize their activities in the context of Green ICT.

1.4. Research objective and questions

This research will lead to a Green ICT maturity model that allows organizations to measure both positive and negative effects of utilizing ICT in an industrial manufacturing setting focused on asset lifecycle delivery processes. Table 1 provides an overview of the main research question and sub-questions. The sub-questions are designed to contribute to the development and validation of the GITMM-MANU. The practical application will allow organizations to measure their current state and develop a roadmap for implementing a higher level of maturity. The result of these activities can lead to lower emissions, better use of resources, and less e-waste.

Table 1: Overview of the main and sub research questions

Subject	Research questions
Overall research	What is a Green ICT maturity model for industrial manufacturing, and asset operations?
Preliminary research	P1. What is industrial manufacturing? P2. What are the most common business processes for industrial manufacturing operations and engineering? P3. What is the potential impact of Green ICT for manufacturing either negative or positive?
Literature review	L1. What is Green ICT? L2. What are maturity models? L3. Which criteria are relevant for Green ICT maturity models? L4. Which criteria are relevant for Green ICT maturity models for the manufacturing industry? L5. Are suitable maturity models available for process manufacturing? L6. Which definitions must be used, adjusted, or added specifically for this model?
Empirical questions	E1 Is the presented model valid for the manufacturing industry? E2. Is the model producing results that can be used for its intended purpose? E3. What is the maturity of Green ICT for the measured organizations?

1.5. Motivation/relevance

This report draws its scientific value from an initial conclusion that specific research towards Green ICT for industrial manufacturing is limited. The Smarter 2030 report describes an opportunity for manufacturing in a timeline of five to ten years to significantly improve their negative impact on the environment through the use of ICT (Global e-Sustainability Initiative, 2015). This report also displays a social application as it will practically contribute to global sustainability challenges. With this report specifically designed around industrial manufacturing, the industry will gain a new management tool and additional insight on how to apply Green ICT.

1.6. DSRM Research approach

The DSRM methodology provides a framework for conducting information system research and developing artifacts such as maturity models. This methodology provides the researcher with principles, procedures, and practices that guide the researcher during problem identification, literature review and empirical research (Peffers et al., 2007). How the DSRM methodology aligns with the outline for this report is explained in Table 2.

Table 2: DSRM and report outline

DSRM step	Report chapter
Identify Problem & Motivate	Chapters 1.1, 1.2, 1.3 and 1.5 identify the problem and provide motivation for the need.
Define the Objectives of a Solution	Chapter 1.4 describes the overall objective and research questions.
Design & Development	Chapters 2 and 3 provide literature research on the topics and development of the GITMM-MANU.
Demonstration	Chapters 4 and 5 describe the design and research results of the empirical phase. The proposed GITMM-MANU is evaluated by demonstration to respondents in the empirical study, which is designed in chapter 4. The results are described in chapter 5.
Evaluation	Chapters 6.1 and 6.2 provide the evaluation of the proposed GITMM-MANU through reflection and conclusions of the research.
Communication	This report will be publicly available and presented as part of the last step before graduation.

1.7. Report Outline

The remainder of this report will start with the preliminary research in chapter 2 to provide the reader with an overview of the industrial manufacturing industry. Chapter 3 will develop the theoretical framework based on the literature review for Green ICT and maturity models. The research methodology in chapter 4 will provide details on how the research will be executed. Chapter 5 will provide insights into the results of the collected data. Chapter 6 will provide the necessary discussion and conclusions on this report through means of reflection and will propose opportunities for further research.

2. Preliminary research

The preliminary research will provide an overview of the focus area of industrial manufacturing. This chapter is a part of the Design & Development step as part of the DSRM methodology. The basis for the chapter is grounded in fifteen plus years of experience by the researcher who works as an information architect for industrial manufacturing organizations.

2.1. What is industrial manufacturing?

Industrial manufacturing is the bulk creation of goods that can be used as end-products or used as input for the manufacturing of other products. A typical example of an industrial manufacturing process is the production of gasoline. The input is crude oil, where the output is gasoline to be used for transportation. Various by-products from the refining process can be used as input for other processes, for example, the bulk creation of plastics.

Industrial manufacturing is time, resource, and capital intensive. Large installations have a very high degree of complexity, can cost up to tens of billions of dollars and five to ten years to develop. Once an installation is in operation, the lifespan of these installations is several decades. A common lifespan of a large installation is 30 to 40 years. The discipline to manage a portfolio of installations is referred to as 'Asset Management'.

2.1.1. Asset Management

Before addressing the lifecycle of an asset, let us review what assets are. Assets are large expensive physical things that provide economic value for a long period of time. Samples of these assets are petrochemical installations, LNG (Liquid Natural Gas) terminals, power plants, offshore exploration vessels, and others. The management of these assets is described as the discipline of asset management. The Institute of Asset Management (IAM) has laid the groundwork for the ISO 55000 standard. This standard has a clear definition of the purpose of asset management, under clause 3.3.1.

- Asset Management: *"the coordinated activity of an organization to realize value from assets"* (IAM, 2015).

As considerable value needs to be derived potentially over decades, it is no surprise that these assets have a long and multiphase lifecycle. Several versions of a lifecycle can be used, however, for the purpose of this report we will use the lifecycle displayed in Figure 1:

Figure 1: Stages in the lifecycle of a physical asset (IAM, 2015)

Based on the definition above, a brief description of the characteristics for an asset lifecycle is listed below:

- ***Identify need*** – based on internal and external factors, organizations define the exact needs for an asset. This process can take several years. Needs identification, for example, can be driven by an economical circumstance such as an expected need for refined oils or a switch in energy use from coal to LNG. Other factors could be more internally driven as the

company is recognizing that certain assets are aging or production is cheaper in other parts of the world.

- ***Design, Construct, Commission –*** Upon identification of the need, organizations can either acquire an asset, or start the development process. If an organization decides to develop, the development process of design, construction, and commissioning is a multiyear project involving large amounts of capital and generating economic value for the region (Douglas, 2019).
- ***Operate and maintain –*** Even as the development or purchase of an asset involves large amounts of capital, this remains a fraction of the ongoing operational cost over the many decades of operation. During its lifespan, there are both negative and positive, economic, environmental, and social impacts on the region.
- ***Decommission and management of residual liabilities –*** Upon decommissioning of the asset, the owner can be responsible for returning the environment to its previous state. The specific activities required are very dependent on the industry, local regulations, and type of asset that is being decommissioned.

Because an asset can be in operation for many decades, the research is focused on the operating and maintenance phase of the asset. The field of asset management is a large multifaceted field and it is beyond the scope of this report to further define this.

2.2. Business processes for industrial manufacturing

Asset management for an operational facility is accomplished via specialists in major management areas that all influence each other on a day to day basis. IAM has defined six major management areas (see Figure 2). In Figure 2 two red circles are added to highlight the focus of this research. One area circles the 'Operate and Maintain' phase as part of lifecycle delivery. This phase has many engineering activities and processes where Green ICT can play a role. The second circle is placed at the bottom of this picture around 'Asset Information'. The asset information block describes the types of ICT systems and tools used by operations and maintenance to safely operate the facility.

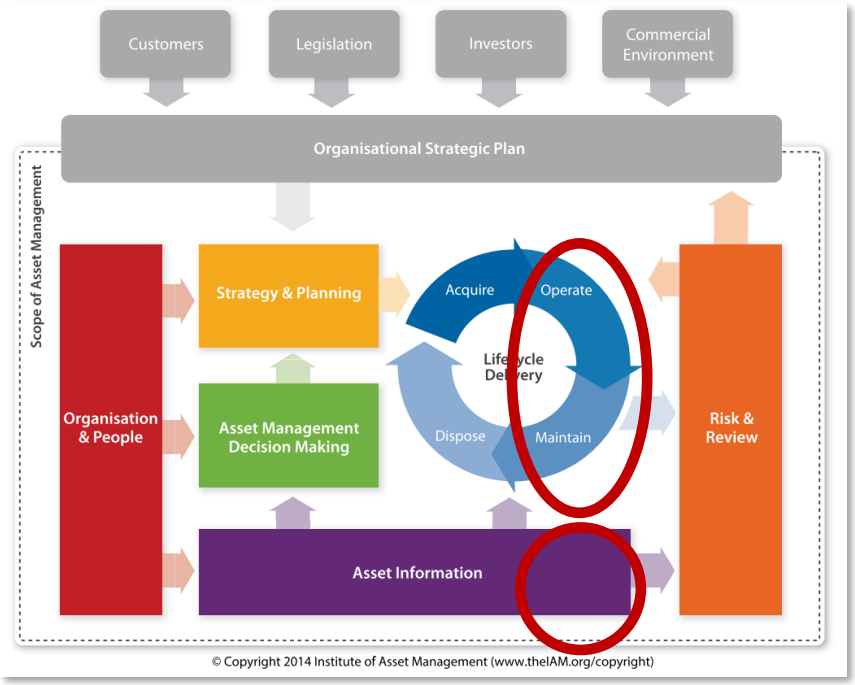

Figure 2: Scope of Asset Management (IAM, 2015)

Every management area contains a subset of topics that need attention for the successful execution of asset management (IAM, 2015). Figure 3 shows the 39 individual subjects in relation to the management areas. The research is focused on the operational phase (lifecycle delivery), the topics from group 3 and group 4 will likely play a key role in the definition of the GITMM-MANU. However, as part of the research question L4 (see chapter 3.3.4), all the topics will be reviewed to determine which topics will be part of the GITMM-MANU.

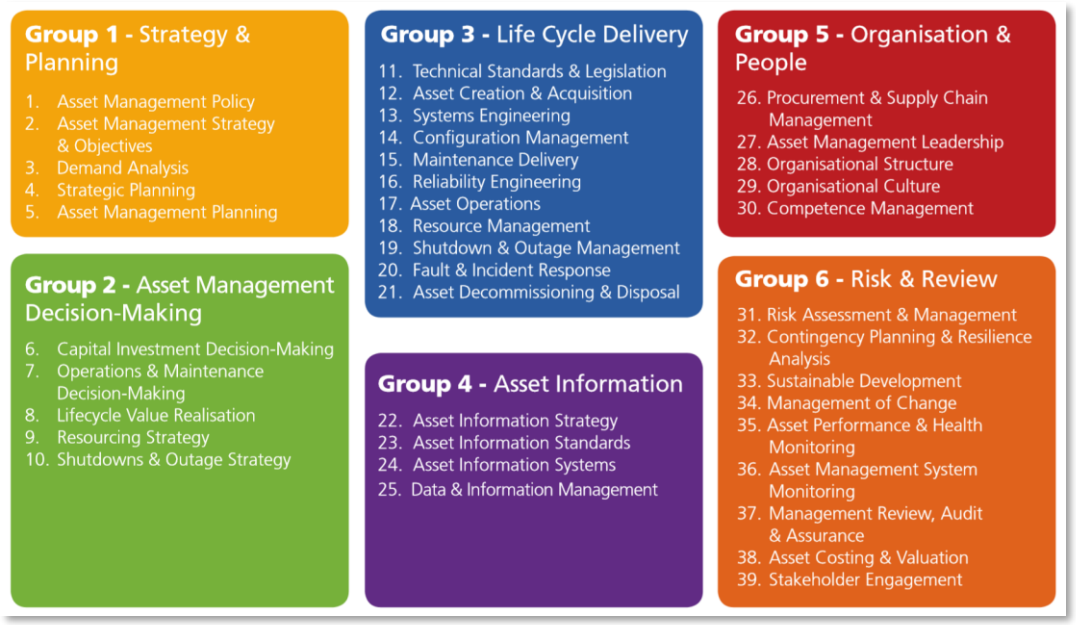

Figure 3: Asset scope with individual topics (IAM, 2015)

2.3. The potential impact of Green ICT for manufacturing

The manufacturing industry is not sustainable in its current form. At present population levels we are utilizing the planet's resources at a rate of 1.5 times in terms of the impact of emissions, depletion of resources, etc compared to the planets capacity. With the world population predicted to grow significantly between 30 to 40% by 2050, there will be an ever-increasing need for more manufacturing as more people will be in a position to afford a western way of life (Hutchins as cited in Dornfeld, 2014). This increase in industrial growth is not sustainable and the question arises to what extent Green ICT can impact this.

The Smarter 2030 report states that smart manufacturing and the industrial internet of things (industry 4.0) are related (Global e-Sustainability Initiative, 2015). Industry 4.0 describes how intelligent systems, processes, and devices can integrate horizontally and vertically whilst optimizing the end-to-end lifecycle of products through the continuous collection and use of data (Acatech as cited in Stock & Seliger, 2016).

Smart manufacturing is the application of industry 4.0 capabilities across several ICT tools to utilize the information collected. Estimated results should lower waste, reduced water usage, more efficient production processes, and integration of the full manufacturing value chain. It is estimated, that by continuously analysing the collected information, new disruptive applications will be found that have a large impact of up to 22% reduction in CO_{2e} emissions before 2030. The Smarter 2030, therefore, provides the following definition for smart manufacturing: *"The intensified application of advanced intelligence systems that create a fully digital value chain"* (Global e-Sustainability Initiative, 2015).

The authors of the Smarter 2030 report are predicting that, for the first time in history, we will be able to decouple economic growth from the growth of energy consumption by the year 2030. This is an important indicator as it will pave the way for a more sustainable future (Global e-Sustainability Initiative, 2015).

2.4. Preliminary research findings

The purpose of preliminary research is to provide insight into the selected subject, before building a theoretical framework on Green ICT, maturity models and manufacturing. The main subject of industrial manufacturing has guided the following research questions that are summarized in Table 3 including the findings.

Table 3: Answers to preliminary research questions

Research question	Finding
P1. What is industrial manufacturing?	Industrial manufacturing is the continuous production of non-discreet items (gasoline, plastics, energy, etc). It is capital intense, with assets having a long and complex lifespan with a high impact on the environment.
P2. What are the most common business processes for industrial manufacturing operations and engineering?	The basis for a definition of processes is based on ISO 55000 (IAM, 2015). From this standard, two management areas are preliminarily identified for inclusion in the GITMM-MANU, based on the focus of the operational phase of an asset: • Group 3 – Life Cycle Delivery • Group 4 – Asset Information A more detailed review as part of the literature study (L4) will reveal in more detail which subjects of these management area's will be included in the GITMM-MANU.
P3. What is the potential impact of Green ICT for manufacturing either negative or positive?	Based on research, there are two distinct findings: • Smart Manufacturing (industry 4.0) is the potential of fully integrating horizontally and vertically the production value chain using digital technologies, which can reduce emissions (up to 22%), lower (e-)waste and establish more efficient production processes. • Through the contribution of ICT innovation, it is predicted that we can decouple economic growth from energy consumption.

3. Theoretical framework

The previous chapter provided background about manufacturing. The theoretical framework will explore the scientific literature that has been peer-reviewed and will provide a thorough background on the scientific fields of Green ICT and maturity models.

As described in the problem statement (see 1.3), the aim is to develop a Green ICT maturity model for the manufacturing industry. Relevant literature is provided at the start, as part of earlier graduation reports performed by OU students (see Appendix 1 – Overview of provided literature).

3.1. Research approach

The research approach is a deductive approach of the literature. Researcher will identify the prevailing theories, choose the most applicable to Green ICT in asset operation, and combine these to create a theoretical maturity model for industrial manufacturing. This model (GITMM-MANU) will then be tested during the empirical part of this research (Saunders et al., 2016, p. 74). The research questions to define the GITMM-MANU are listed in Table 4 below.

Table 4: Overview of literature research questions

Research question	Purpose of the question	Search Method
L1. What is Green ICT?	The literature review on Green ICT will provide additional validity to the report and reveal the latest insights into the topic.	Forward snowball
L2. What are maturity models?	The literature review on maturity models will provide additional validity to the report and reveal the latest insights into the topic.	Forward snowball
L3. Which criteria are relevant for Green ICT maturity models?	Green ICT has many different aspects and the literature will review the relevant criteria for Green ICT and maturity.	Building Blocks
L4. Which criteria are relevant for Green ICT maturity models for the industrial manufacturing industry?	Literature will be used to further review the criteria specified for the manufacturing industry.	Building Blocks
L5. Are suitable maturity models available for industrial manufacturing?	Based on the outcome from the previous questions, the report will answer if Green ICT maturity models exist for industrial manufacturing.	Building Blocks
L6. Which definitions must be used, adjusted, or added specifically for this model?	Based on the outcome of the previous questions, a review will take place if and how definitions need to be adjusted for the applicability of the model for industrial manufacturing.	Building Blocks

For each question, L1 through L6, the approach for performing a critical review of the literature is different. The questions are grouped and the approach per group is explained below:

Group 1 – Forward snowball – For the first group, questions L1 and L2, the approach is based on the snowball method. Existing literature has been provided as part of a larger initiative led by Dr. Anda Counotte - Potman. This initiative has a focus on Green ICT, sustainability, and maturity where several graduate students have recently performed research on the same topic but with a different industry focus. The next step will be to use forward snowballing (Thomé et al., 2016) to find related articles to provide different insights to these questions. An overview of the provided articles is made available (see Appendix 1 – Overview of provided literature).

Group 2 - **Building blocks**– For this second group, questions L3 to L6, search queries were defined based on the building blocks method to locate relevant literature. For question L3 there is available literature, however, the literature provided was limited. The definition of the search queries is detailed in (see Appendix 2 – Search query definitions).

3.2. Implementation

3.2.1. Group 1 – Forward snowballing

The supplied articles from the OU, were categorized into three main categories, Green ICT, Green ICT & Maturity, and Maturity. For each article, the amount of citations has been listed as found via Google Scholar and the OU library. For each category, the top 3 articles with the highest combined citations were evaluated for additional relevant literature. Table 5 below provides an overview of these results.

Table 5: Cited articles per category

Topic	Article title	Total Citations
Green ICT	Harnessing Green IT - Principles and Practices	1210
	A capability maturity framework for sustainable information and communication technology	151
	The Green IT readiness (G-readiness) of organizations: An exploratory analysis of a construct and instrument	99
Green ICT & Maturity	Understanding the Maturity of Sustainable ICT	36
	A Maturity Model for Green ICT: The case of the SURF Green ICT Maturity Model	24
	Green ICT Maturity Model for Czech SMEs	16
Maturity	Capability Maturity Model, Version 1	2689
	Developing Maturity Models for IT Management	644
	What makes a useful maturity model? A framework of general design principles for maturity models and its demonstration in business process management	233

For the articles listed in Table 5, the forward snowballing method was utilized to find relevant articles for each category. The selection of articles for review was therefore based on the combined criteria below:

- Citation count
  If multiple forward snowball articles were present, the article with the highest citation count is considered. If there was no citation, then the publication date is taken for relevance.
- Publication date
  The search was limited to publication date in the last 5 years (Jan/1/2014 or newer) to find articles that are relatively new.
- Title construct
  The title needed to clearly indicate that there was a relation with the field of Green ICT and or, maturity models and potential relevance to this research.

Based on these criteria, an additional nine articles were selected for the critical review towards addressing questions L1 and L2 (see Appendix 3 – Forward snowballing, selected articles for review of L1 and L2).

3.2.2. Group 2 – Search Queries

For the second group, query definitions are utilized to find suitable articles to address questions L3 to L6. Based on the initial search results in the libraries available through the OU and Google Scholar, the searches went through several iterations of refinement and adjusting of the queries and parameters. For the OU library, the advanced option was used to enter the details of the search queries as defined (see Appendix 2 – Search query definitions).

Each time the search was performed, the recipe in Figure 4 was followed to ultimately select articles for further review. The same recipe was executed for both the libraries' Google Scholar and OU. The searches were performed on September 28 and 29, 2019.

Based on the results for each iteration, the parameters were adjusted slightly to tune the results for titles that sounded more and more promising. The exact search iterations and results are made available (see Appendix 4 – Search iterations).

With each result set, a great number of titles were scanned for potential suitability. Once a title was deemed worthy, the details for this article where placed in an excel spreadsheet, and the article with its citation were downloaded into the application Mendeley for desktop. If the article was directly available, the article was uploaded into the Mendeley application. If the article was not available, an additional search using Scihub[1] was performed to retrieve the content. Using this method, most of the articles have a document associated in the Mendeley database.

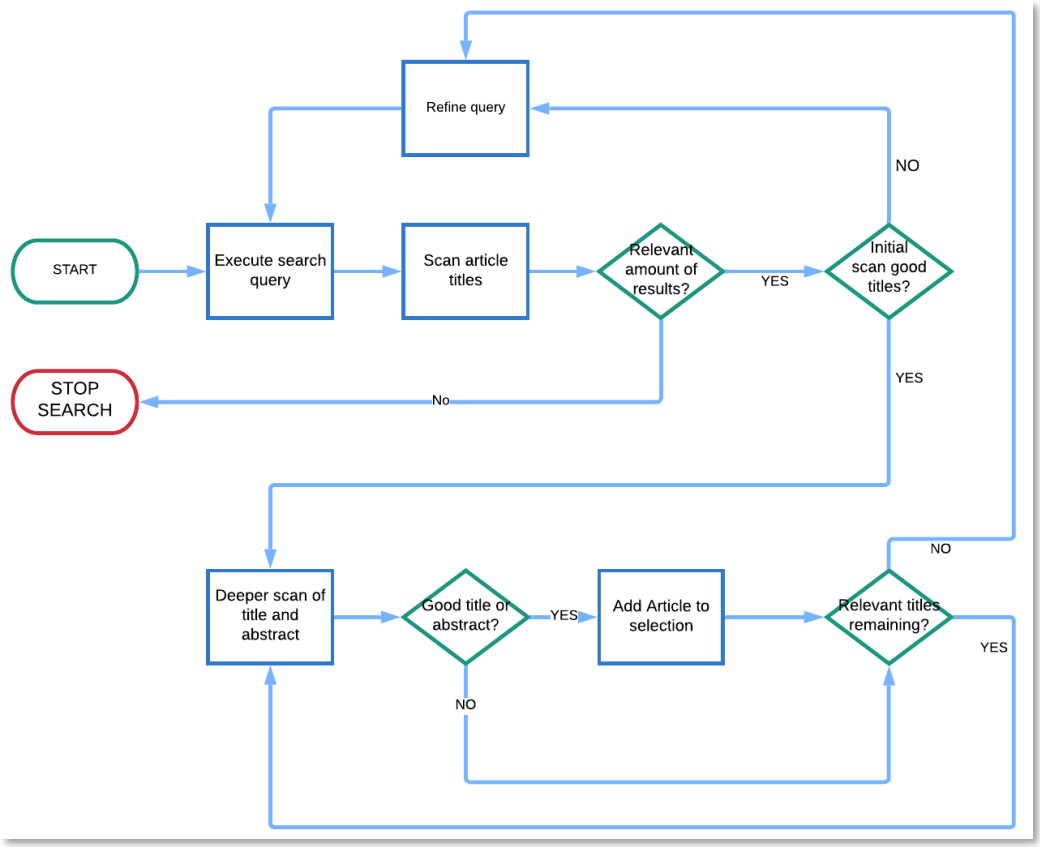

Figure 4: Search recipe

[1] Sci-Hub is a website that provides free access to millions of research papers and books, without regard to copyright, by bypassing publishers paywalls in various ways. Source: Wikipedia.

Upon completion of the searches, a further analysis took place. Based on the list of articles that were selected, after removing the duplicates, there was a list of 94 articles for which the title sounded promising to answer the questions L3 through L6. The 94 articles were further evaluated by looking at the abstract, publication year, keywords, citations and by scanning the full article. To determine the relevance for this research, every article has been categorized based on important topics. Articles without the full text and articles in a language other than English or Dutch have been omitted by default.

Each article has been assigned 1 or more categories as listed below. The score for the article was based on adding the points for each category. More points were assigned for specific topics more applicable to this research.

The categories and associated point assigned are listed below:

- Sustainability, 1 point
- Green ICT, 3 points
- Maturity Model, 3 points
- Manufacturing, 1 point
- Process Manufacturing, 3 points

An overview of all selected titles, their score, and other details is available (see Appendix 5 – Search results for L3 through L6).

3.3. Results and conclusions

Based on found literature as defined for group 1 and group 2, the research answers the defined research questions. The combined result of the theoretical research questions (L1 to L6) is the theoretical Green ICT maturity model for industrial manufacturing (GITMM-MANU). How the literature research has led to the theoretical model is visible in Figure 5.

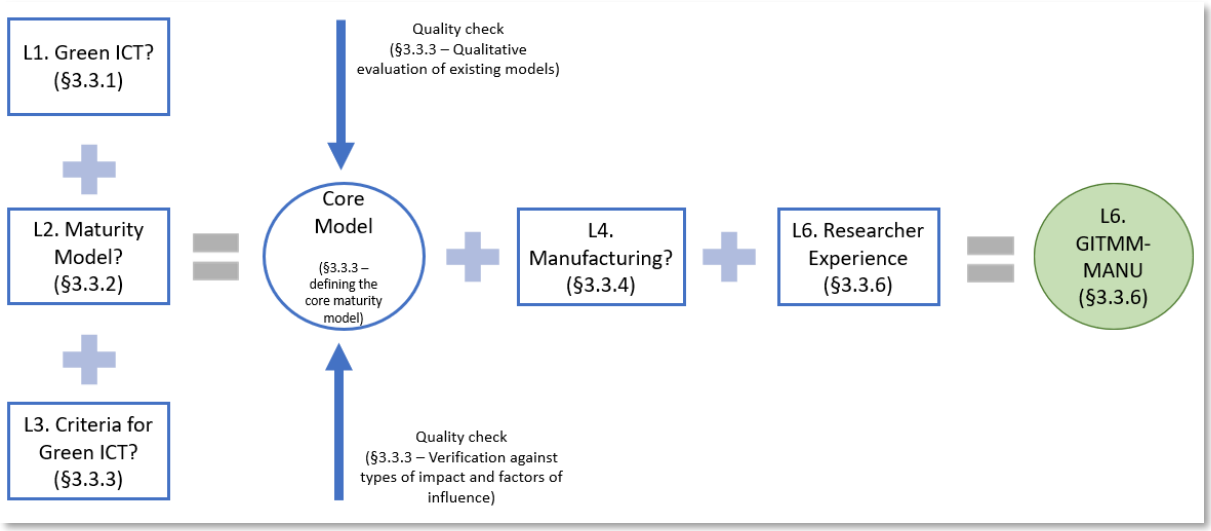

Figure 5: Theoretical development steps for the GITMM-MANU

3.3.1. L1. What is Green ICT?

This report started in chapter 1.2.1, by explaining that Green ICT is a relatively young research field. The conclusion was that ICT is both a part of the environmental problem (Green in IT) as well as a solution to the environmental challenges humanity currently faces (Green by IT). As an example,

technology has disrupted how businesses collaborate across large distances. New technologies have greatly reduced the need for travel, which in return have a positive effect on the environment.

Based on the outcome of the forward snowballing method, nine articles (see Table 19) provide detailed insights into the topic of Green ICT. For further development of the GITMM-MANU, we need to understand what effects Green ICT has, how is Green ICT influenced, and what the benefits are for an organization. The knowledge from these articles, combined with earlier Green ICT maturity models will form the basis for the constructs.

The impact of ICT can be classified as the type of effects and in what order these effects happen. Köhler & Erdmann describe these effects as primary, secondary and tertiary effects (Köhler & Erdmann, 2004). Where primary effects are focused on the physical existence of ICT (Green in IT). The secondary effects are focused on the impact ICT can have due to its ability to enforce change (Green by IT). Thirdly, there are tertiary effects, which describe environmental effects due to medium- and long-term adaptation of behaviour instigated by ICT. With this classification in mind, Hilty further refined this classification to also include if and how the effects are negative or positive. His work has provided a holistic framework that describes the order of these effects, and if these effects are positive or negative (Hilty & Aebischer, 2015a). This is conceptually displayed in Figure 6.

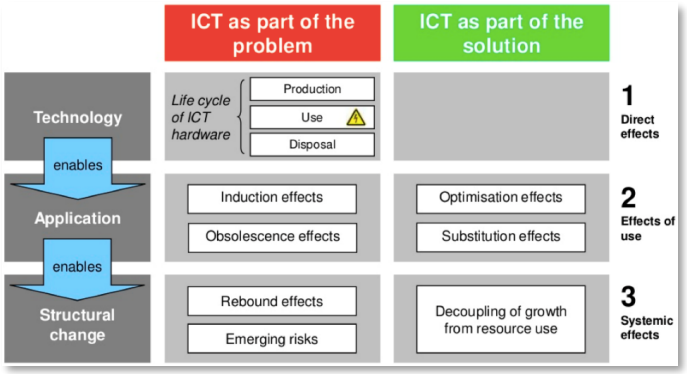

Figure 6: Framework of the impact of IT on the environment (Hilty & Aebischer, 2015a)

Equipped with the above information, Hankel et all., developed a detailed taxonomy of the factors that influence the environmental impact of ICT (Hankel et al., 2018). Through their work, they describe 5 types of impact. The 5 types of impact work in tandem, where the effects of one type of impact, influence the effects on the next type of impact. A condensed overview of these types of impact and how these are influenced are available in Table 6.

Table 6: Types of impact and factors of influence for Green ICT (Hankel et al., 2018)

Type of impact	Factors of influence
Direct Impact of ICT / Direct effects	Design, Production, Packaging, Procurement, Use of ICT, E-Waste
Indirect impact of ICT / Effects of use	Teleworking and Collaboration, Paper reduction, Smart buildings, Smart energy, E-commerce, Smart motors, Smart logistics, Feedback, and reporting
Systematic impact of ICT / Systemic effects	Adoption, Innovation
Organizational impact on ICT	Culture, Strategy, External Interaction, Current State, Governance, Green ICT business case, Corporate policies, Use of renewable energy
Societal impact on the organization	Compliance, Transparency, Market Forces, Reputation, Environmental Risks, Uncertainties

Understanding the various effects of Green ICT, and how Green ICT can be influenced, there is a remaining question of, "What's in it for me?" Loeser et all., describe that because of a poor understanding of the Green ICT benefits, executives are struggling to launch Green ICT initiatives. The positive outcome, based on the findings from 118 global IT executives is that, Green ICT provides cost reductions, improved corporate reputation, and Green innovation capabilities (Loeser et al., 2017).

By combining the work from Hilty, Hankel, and Loeser, the researcher developed a conceptual framework that provides a holistic view of Green ICT for an organization. The framework shows the negative and positive effects of ICT. As an additional dimension, it shows an overview of how technology enables the use (application) of ICT, which in turn can lead to structural change. How the different layers can be influenced, is shown in the column factor of influence and the organizational and societal impact (see Figure 7).

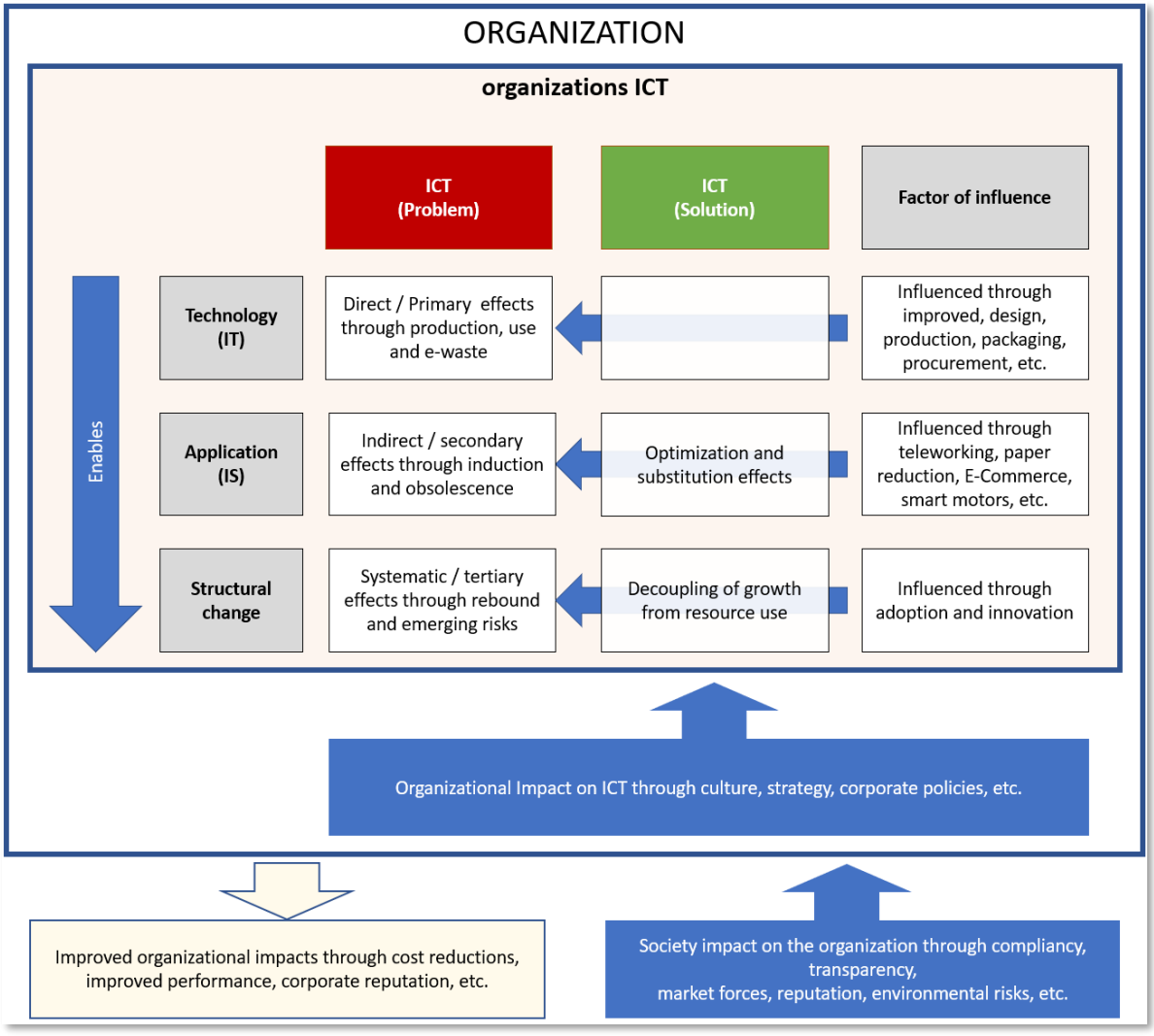

Figure 7: Green ICT and its role in the organization

The framework in Figure 7 provides an overview of Green ICT, it will be used to understand how well (or poorly) the different elements are represented in the GITMM-MANU.

To summarize the research question: Green ICT is a complex multidimensional construct that

reaches far beyond the technology component. When it is well managed, it has the capacity of far-reaching societal changes.

3.3.2. L2. What are maturity models?

During the early '90s, maturity models were developed to improve the quality of software development. Although a lot of research has been done towards the application of maturity models, less research is done to provide a generic definition. With this lack of a generic definition, Wendler turned to the Oxford definition of maturity and capability to put in perspective what the purpose of a maturity model is (Wendler, 2012).

- *Maturity, ''The state of being mature; fullness or perfection of development or growth''*
- *Capability, "power or ability in general, whether physical or mental to fulfil specified tasks and goals''*

With these definitions in mind and looking back at the initial CMM, Paulk was rooted in the belief that if the process would be improved, the outcome of the process, being the quality of the software, would be improved as well (Paulk et al., 1993). The intent of a maturity model is, therefore, to understand the current capability of an organization and determine a path for maturing that capability on a specific topic. It is easy to recognize how the Oxford definitions are closely aligned with the early definition of the CMM model and have stood the test of time. Becker et al, provide the following definition which captures the essence of maturity models (Becker et al., 2009).

- **Maturity model:** A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes.

Wendler describes that from 2003 to 2010, the number of articles has grown considerably year over year. Maturity models are immensely popular, but there is a reason to remain critical in their approach to development and application. Wendler debates the practical use of maturity models. Many of the models were lacking proper validation of the structure and applicability. This concern questions the usefulness of the model in a practical setting (Wendler, 2012).

To ensure a quality maturity model, the following measures are put in place to:

- The research follows a structured methodology, DSRM (see 1.6).
- The GITMM-MANU will be reflected against the concepts of Green ICT (see Figure 7, 3.3.1).
- Existing maturity models used as a base for this model are evaluated against design principles (see 3.3.3).
- The GITMM-MANU uses an ISO standard for the specific components of manufacturing (see 3.3.4).

3.3.3. L3. Which criteria are relevant for Green ICT maturity models?

Academics have criticized the value of maturity models in terms of quality and validity for different reasons (Mark, 2014; Pöppelbuß & Röglinger, 2011; Wendler, 2012). Both Green ICT and maturity models are multi-layered as well as multidimensional, therefore defining the criteria for a Green ICT maturity model requires a thoughtful and structured approach.

Qualitative evaluation of maturity models

An often-cited approach is explained by Pöppelbuß where multiple design principles are presented in the form of a checklist for both the validation of existing work as well as the development of a new framework (Pöppelbuß & Röglinger, 2011). To this research, the design principles will be used to qualitative evaluate the different maturity models found during the literature research. The design principles categorize maturity models into three major classes, descriptive, prescriptive, and comparative. Descriptive models are useful to determine the current state but do not provide elaborate guidance on how to mature from one state to the next. Prescriptive models are more detailed in nature as they will guide the user on how to move from one state to the next by defining the criteria required to mature to the next level (Becker et al., 2009). Comparative models allow for internal and external benchmarking, assuming there is enough historical data from a large number of assessments (Maier et al., 2009).

To find the most suitable work for further development of the GITMM-MANU, the design principles will be used as a scoring method to rate the quality of the maturity models found during the literature research, see Table 23 (Pöppelbuß & Röglinger, 2011). Furthermore, the constructs utilized in the highly rated models will be qualitatively evaluated to determine the criteria required for the GITMM-MANU. The method for the qualitative evaluation is based on the conceptual framework presented in Figure 7. The framework describes different factors of influence that influence Green ICT for an organization. The proposed GITMM-MANU should cover as many influences as possible to develop a holistic picture of the maturity. As such, this is a second quality check for the GITMM-MANU specific to the topic of Green ICT.

Selection of existing suitable maturity models

The 94 articles that were selected as part of the literature review have been screened for initial applicability by reviewing the titles in more detail and performing several reads of the abstract and a cursory review of the article. Based on this activity, a subset of 41 articles remained which were further screened to determine if the article described was an actual Green ICT maturity model and based on the CMM principles. After removing duplicates, a subset of 10 models remained that can be classified as actual Green ICT Maturity models. These remaining 10 models have been evaluated against the design principles from Pöppelbuß to determine a score, see Table 7 (Pöppelbuß & Röglinger, 2011).

All design principles are valued equally, with a maximum of 15 points for descriptive models and 18 points for prescriptive models. Researcher has evaluated applying different weightings for the basic, descriptive and prescriptive principles, but this did not lead to a significant change in the outcome. Table 7 provides an overview of the evaluated models and the total score for each article, the articles are sorted by their score (high to low) and the title of the article (a to z). Table 22 provides how the scoring was applied for each model in relation to each design principle.

Based on the detailed review of the selected models, it is noticeable that there is a lot of difference in the quality and approach for the models. To determine the actual criteria for the theoretical GITMM-MANU, the top three highest scoring models will be contrasted.

Table 7: Ten remaining maturity models rated based on design principles from Pöppelbuß

Article title	Citation	Score
A maturity model for Green ICT: The case of the SURF Green ICT maturity model	Hankel, A., Oud, L., Saan, M., & Lago, P. (2014). A maturity model for Green ICT: The case of the SURF Green ICT maturity model.	14
Assessing and Managing an Organization's Green IT Maturity Making.	Sang-Hyun, P., Jaekyung, E., & Joosung, J. L. (2012). Assessing and Managing an Organization's Green IT Maturity Making. MIS Quarterly, 11(3), 127–140.	14
A comprehensive and practical Green ICT framework	Philipson, G. (2010). A comprehensive and practical Green ICT framework. In Handbook of Research on Green ICT: Technology, Business and Social Perspectives (pp. 131-145). IGI Global.	12
Green IT framework for small and medium scale Indian IT services companies	Mohapatra, S., & Jindal, A. (2010). Green IT framework for small and medium scale Indian IT services companies. International Journal of Green Economics, 4(3), 245-261.	11
Green ICT maturity model for Czech SMEs	Buchalcevova, A. (2015). Green ICT maturity model for Czech SMEs. Journal of Systems Integration, 6(1), 24-36.	9
CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY	Viaro, T. A., Vaccaro, G. L. R., & Scherrer, T. (2011). CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY. Proceedings of XVII ICIEOM, Belo Horizonte, Brazil, 4-7 October 2011.	7
From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations	Erek, K. (2011). From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations. In European, Mediterranean & Middle Eastern Conference on Information Systems (Vol. 2011, pp. 766-781).	5
Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach	Deodhar, S. J., & Saxena, K. B. C. (2011). Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach. FIIB Business Review, 1(1), 48-53.	4
Assessing Green, its maturity and providing Green IT recommendations	Desai, M. A., Bhatia, V., Kolli, S., & Raman, A. (2013). U.S. Patent Application No. 13/316,208.	4
A capability maturity framework for sustainable information and communication technology	Donnellan, B., Sheridan, C., & Curry, E. (2011). A capability maturity framework for sustainable information and communication technology. IT Professional, 13(1), 33-40. doi:10.1109/MITP.2011.2	3

A maturity model for Green ICT: The case of the SURF Green ICT maturity model – 14 points - (Hankel et al., 2014)

The SURF Green ICT model is developed to support the Dutch higher education institutions in assessing their maturity in terms of Green ICT. Based on a panel of nine Green ICT experts, the initial framework was established. To further validate the model, an online survey was designed, which was completed by 20 subject matter experts from the higher education industry in the Netherlands. The SURF model is designed with extensibility in mind for different industries. The SURF model describes four distinct domains, Green ICT in the organization, Greening of ICT, Green of operations with ICT, and Greening of industry-specific primary processes to support the industry-specific nature. The SURF model is the most recent model based on the literature review. Frequent publications are available from the original author on the topic of Green ICT. Not only the original author, but other graduate students and researchers have used the SURF model in recent years as a basis for further research. From this, the SURF model seems to be the most up to date and more work is available based on this compared to the other models. The SURF model is licensed under creative commons 3.0 and publicly available including manuals for use.

Assessing and Managing an Organization's Green IT Maturity Making – 14 points - (Sang-Hyun et al., 2012)

The Sang-Huyn model is developed in 2012 and has a theoretical and subject matter expert background. The Sang-Huyn model is developed by deducing an extensive list of criteria from earlier work from Accenture, the U.K. Government's Green ICT scorecard, and the connection research RMIT model discussed earlier. All three of these earlier models have been extensively used in a practical setting. The resulting criteria have been validated amongst 36 Korean Green ICT experts and weighting was applied using the analytical hierarchy process (AHP). The Sang-Huyn model provides prescriptive descriptions for what the different levels mean and what is required to establish the next maturity level.

A comprehensive and practical Green ICT framework – Connection Research-RMIT Green ICT Framework – 12 points – (Philipson, 2010)

The Philipson model is developed in conjunction with RMIT University in Melbourne Australia and a commercial company, Connection Research. Being the oldest model, it shows the highest level of practical validation with over 500 organizations assessed globally. Although the Philipson model describes both Green by IT as well as Green in IT, three of the four pillars are focused on Green in IT. The article available did not provide enough detail to understand the theoretical background, how the criteria were established and to what extent the criteria are either descriptive or prescriptive. The Philipson model draws from earlier research conducted by the RMIT University towards a readiness model for Green ICT. Beyond the original publication, no newer versions of the Philipson model seem to be distributed, and since there is no detailed information regarding the criteria and how the Philipson model contrasts to other models, the scoring resulted in twelve points (Philipson, 2010).

Defining the core maturity model

Based on the review of the top three models, the detailed building blocks for the GITMM-MANU have been established by utilizing the work from both the SURF model from Hankel as well as the model from Sang-Hyun to define a unique set of building blocks (Hankel et al., 2014; Sang-Hyun et al., 2012). The reason for utilizing both the models is that the model from Sang-Hyun has extensive practical value and it is rooted in many years of consulting experience from global firms combined with expert input from a wide panel. The Hankel model is several years newer and draws its input from an expert panel which was validated and used in a practical setting. The Hankel model was developed with extensibility in mind for industries other than just the higher education industry. Secondly, it was developed to focus more on the utilization of ICT and its contribution to sustainability versus making ICT more sustainable (Green in IT). Recent research from Hankel also greatly influenced the conceptual model in Figure 7, further highlighting current contributions to the field. The model from Connection Research (Philipson, 2010) has been excluded since this model has been extensively reviewed as part of the development created by Sang-Hyun (Sang-Hyun et al., 2012). In Figure 7, a conceptual framework is presented for Green ICT and its role in the organization. If the proposed GITMM-MANU covers many of the aspects presented in a balanced manner, this is an indication of the quality and completeness of the proposed model.

To determine the core GITMM-MANU, we have combined both models and eliminated building blocks that are overlapping, or not applicable anymore. Table 8 provides an overview of the removed building blocks and why these have been removed.

Table 8: Components removed from the Green ICT model

Source	Removed building block	Reason for removal
Hankel	Environmental Awareness and Decision Support	The model from Sang-Hyun has two different elements that describe this topic. Based on the description from Hankel, there was not enough unique distinction to keep both.
Hankel	Green ICT architecture Principles	The model from Sang-Hyun has a very similar component that describes the applicability of a Green agenda and how leadership is organized around a defined set of rules and management system.
Sang-Hyun	Space reductions with ICT	The model from Hankel has a similar component which is used over the description from Sang-Hyun.
Sang-Hyun	Other reductions with ICT	This component is removed, partially because it is too open-ended and not precise enough. Secondly, the model from Hankel describes several elements such as feedback, and decision support as well as the integration of the supply chain that look beyond the own organization. This seems to be a more rounded approach.

The combined model uses certain terminology to describe the GITMM-MANU and how these building blocks are related. Figure 8 describes these elements. Within this figure we can see the following definitions:

- **Domain**
  The domain is the highest level in the GITMM-MANU. There are four different domains, which are:
  - Green ICT in the organization, to measure how the ICT organization approaches Green.
  - Green of ICT, to measure how the physical elements of ICT (computers, servers, etc) are approached.
  - Greening of operations with ICT, to measure how the organization, in general, utilizes Green and the use of ICT.
  - The last domain is sector-specific, which will be specifically developed for the manufacturing industry.

  The domain definitions are derived from the model from Hankel (Hankel et al., 2014)

- **Attribute**
  Every domain has at least one or more attributes. Each attribute describes a domain-specific aspect of Green ICT, for example, 'waste management' as part of the third domain.
- **Component**
  Each attribute has one or more components; the component is the lowest level in the GITMM-MANU and describes a specific item that is being measured (e.g. 'Incentives for waste reduction').
- **Question / Description**
  Each component has one specific explanation which is an elaboration in the form of a question or description (e.g. 'Does your company have incentive and information programs for reducing IT-related waste production, and are these programs conducted effectively?').
- **Maturity Score**
  Each component has one maturity score. The maturity score is a scale from 0 to 5 to measure the level of maturity (Philipson, 2010).

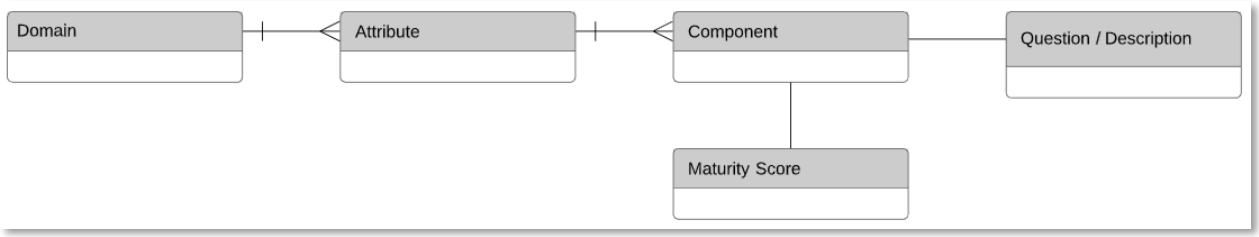

Figure 8: Metamodel for GITMM-MANU

Based on the combined models, the research established a core model that covers 83 components in three domains. Recent research has been done into the different factors that influence Green ICT (Hankel et al., 2018). Figure 7 describes how factors of influence have an impact on how the organization approaches Green ICT.

Verification against the types of impact and factors of influence

As a matter of validation, the factors of influence are mapped to the components in the GITMM-MANU (see Table 24). The purpose of the validation is to understand how well (or poorly) the factors of influence are represented in the GITMM-MANU. If the GITMM-MANU only represents a very limited set of factors of influence, it will arguably be more difficult for an organization to implement Green ICT. The assignment of the factor of influence with a specific component is based on an assessment made by the researcher.

The results of this assessment are visible in Figure 9. For each domain, the main attributes (yellow blocks) are shown. Each attribute is then linked to one or more types of impact (orange blocks). Table 6 in chapter 3.3.1 explains how types of impact and factors of influence are related.

The percentages in the diagram (relative size within the domain) represent the number of components within a domain that measure something for that attribute. For example, the first domain has a total of 28 components. From the 28 components, 16 components are classified as a *'Direct Impact of ICT'*. This represents 57% within this domain.

In the next chapter (3.3.4), the researcher further defines the criteria for the fourth domain. For completeness, the results from this exercise have been incorporated, to present a complete picture of the GITMM-MANU and the factors of influence, see Figure 9. A larger version of Figure 9 is available in Appendix 8 – Green ICT Framework and types of impact.

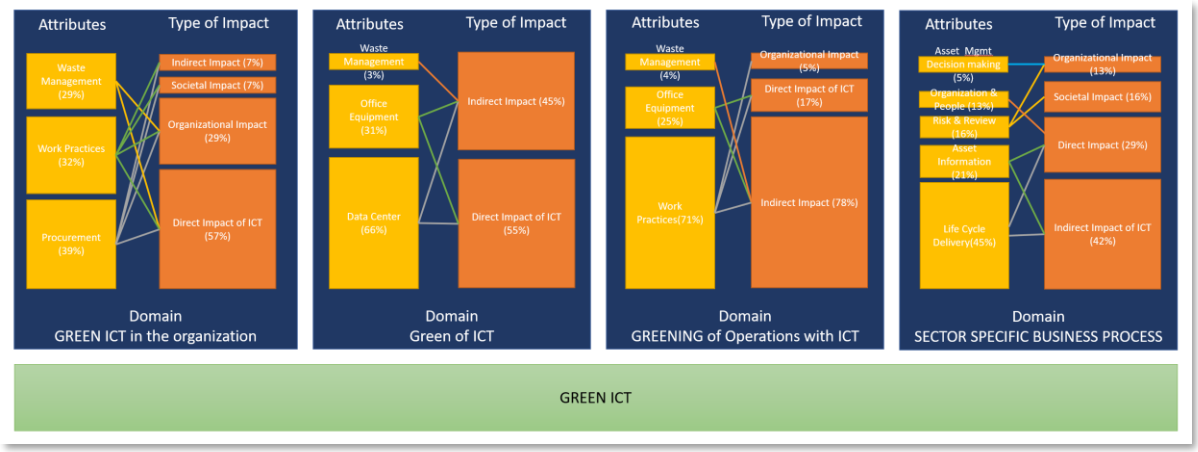

Figure 9: Proposed GITMM-MANU framework combined with types of impact (Hankel et al., 2018)

Based on the assessment several conclusions can be drawn:

- Many types of impact and by extension factors of influence are represented in the GITMM-MANU, which builds confidence for the validity.
- Based on the mapping of the components with the factors of influence (see Table 24), the systematic effects are not represented in the GITMM-MANU. The types of effects where researched at a later point in time (2018) compared to when the models from Hankel and Sang-Hyun were developed (2014, 2012).
- At 39% total, a lot of focus in the GITMM-MANU is on direct impact. Many of the components, however, refer to topics such as energy savings of the ICT organization (servers, network, consolidation, etc). One could argue that future models should investigate the impact of cloud, microservice offerings, and other innovative technologies that have an impact.
- At 43% total, the indirect impact is well represented in the GITMM-MANU to measure what companies do to optimize their operations (generic and specific). A lot of emphasis is placed on paper reduction. For future versions of the GITMM-MANU, emerging areas like RPA (robotic process automation)[2] could be investigated and its relationship with Green ICT.
- At 4% total, societal impact is very poorly represented in the GITMM-MANU. Based on the introduction of this report (see chapter 1), many external factors have an influence on an organization's sustainability efforts. The empirical phase of this study can potentially provide more input on potential factors for future versions of the GITMM-MANU.
- At 14% total, the organizational impact such as culture, strategy, policies, etc. is arguably not represented enough. Although the input from IAM (IAM, 2015) provided direction on organizational impact, more work can be done to develop a more rounded GITMM-MANU in this area.

The results of the assessment are also placed in Table 9. This table shows how well (or poorly) a specific factor of influence is represented in the GITMM-MANU across the four domains.

Table 9: Representation of factors of influence in the GITMM-MANU

Type of impact	Factor of influence	Represented in GITMM-MANU (%)
Direct Impact of ICT / Direct effects (39%)	Design	-
	Production	3%
	Packaging	-
	Procurement	4%
	Use of ICT	29%
	E-Waste	3%
Indirect impact of ICT / Effects of use (43%)	Teleworking and Collaboration	6%
	Paper reduction	17%
	Smart buildings	3%
	Smart energy	12%
	E-commerce	1%
	Smart motors	1%
	Smart logistics	1%
	Feedback and reporting	2%
Systematic impact of ICT / Systemic effects	Adoption	-

[2] Wiki: Robotic process automation (or RPA) is a form of business process automation technology based on metaphorical software robots (bots) or artificial intelligence (AI) workers.

Type of impact	Factor of influence	Represented in GITMM-MANU (%)
	Innovation	-
Societal impact on the organization (4%)	Compliance	1%
	Transparency	1%
	Market Forces	-
	Reputation	2%
	Environmental Risks	-
	Uncertainties	-
Organizational impact on ICT (14%)	Culture	2%
	Strategy	4%
	External Interaction	2%
	Current State	-
	Governance	2%
	Green ICT business case	-
	Corporate policies	3%
	Use of renewable energy	1%

Defining the CMM Scale

With the components of the GITMM-MANU established, a method for measurement needs to be created. Measuring the maturity of each component is based on the CMM introduced in the early '90s (Paulk et al., 1993). The original CMM model describes increasing maturity as a series of steps, where each step on the ladder represents a higher level of maturity. The initial model describes five steps: initial, repeatable, defined, managed, and optimizing. Each step represents a value of maturity from 1 through 5. By averaging the ratings for each component, a maturity score can be shown for the whole organization, per domain and across individual attributes. When multiple organizations are measured, the same principles apply across these organizations (Saunders et al., 2016, p. 528). Since certain topics can be unknown to the organization an additional level zero is added to indicate that there is no intention for this component. The CMM model applied is the model from Connection Research (Philipson, 2010) and is displayed in Figure 10.

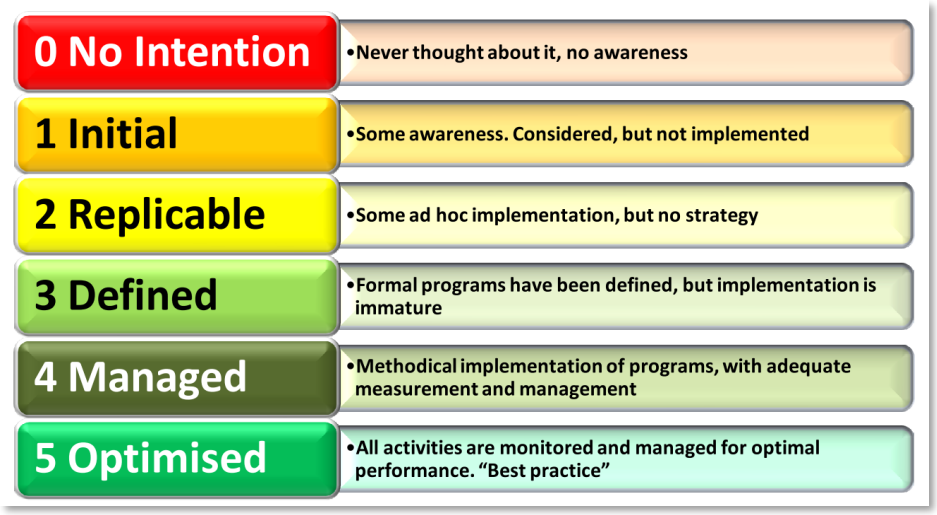

Figure 10: CMM Scale (Philipson, 2010)

Through the definition of the core Green ICT criteria, combined with a scoring mechanism, an initial core model is established. The next question is how this model is applicable to the manufacturing industry and which criteria are relevant to the manufacturing industry.

3.3.4. L4. Which criteria are relevant for Green ICT maturity models for the manufacturing industry?

The Institute of Asset Management provides a detailed insight into the inner workings of asset management as a discipline, the processes to manage an asset from a whole lifecycle approach are defined by the institute (IAM, 2015) as explained in chapter 2.2. The IAM model defines 6 major process groups, each containing multiple subjects for a total of 39.

The subjects important for the purpose of this research are focused on the operational aspects for an asset. Although this draws attention to group 3 and group 4 from the IAM model, after a review of all process groups, several additional process groups are identified for inclusion in the GITMM-MANU. In Figure 11, the subjects selected for inclusion in the GITMM-MANU are highlighted. To include a specific subject (or not), each subject has been evaluated, researcher has estimated the potential impact for Green ICT in the context of the operational lifecycle (see Appendix 9 – Review of criteria for manufacturing industry).

Based on this selection, the GIMM-MANU has been enhanced with additional questions that align with the subjects described. Like chapter 3.3.3, the detailed subjects and related questions are rated against the factors of influence (see Table 24).

Figure 11: Criteria for GITMM-MANU highlighted (IAM, 2015)

3.3.5. L5. Are suitable maturity models available for industrial manufacturing?

As part of the literature search and review of the many articles, a select group of articles showed a clear relationship specifically for the manufacturing industry. From the 94 articles, 15 articles had a relationship with manufacturing. From these 15 articles, some showed a maturity model and relationship with sustainability but were either focused on discrete manufacturing or focused purely on energy reduction of the physical asset. None showed a clear maturity model that could be used as inspiration or as a basis for this research (see Appendix 10 – Manufacturing Articles). Based on the current literature and review efforts, no suitable maturity models are available for industrial manufacturing and Green ICT.

3.3.6. L6. Which definitions must be used, adjusted, or added specifically for this model?

For the development of the GITMM-MANU, the models from Hankel and Sang-Hyun are used (Hankel et al., 2014; Sang-Hyun et al., 2012). The main domain definitions from the model from Hankel are used as a high-level categorization. Within this categorization, the domains from Sang-Hyun are mapped to develop a hierarchy of constructs with corresponding attributes. The model from Hankel specifically allows for a specific domain to be developed to incorporate sector-specific processes. The sector-specific processes are defined with the input from IAM (see question L4 from the literature study). This resulted in 38 additional components specifically for industrial manufacturing and Green ICT. The completed GITMM-MANU is graphically presented in Figure 12.

In the developed Green ICT framework (see Figure 12), attributes and components are grouped slightly differently for the first 3 domains, compared to the last domain. For the domains 1 to 3, the yellow area represents a logical grouping of attributes and the attributes themselves are presented in the white blocks. For the last domain, the yellow area, represents the process groups from IAM (translated to attributes), where the white blocks are logical groupings (IAM subjects) for the components. For example, under 'Asset Information', the strategy block represents several individual components specific to strategy.

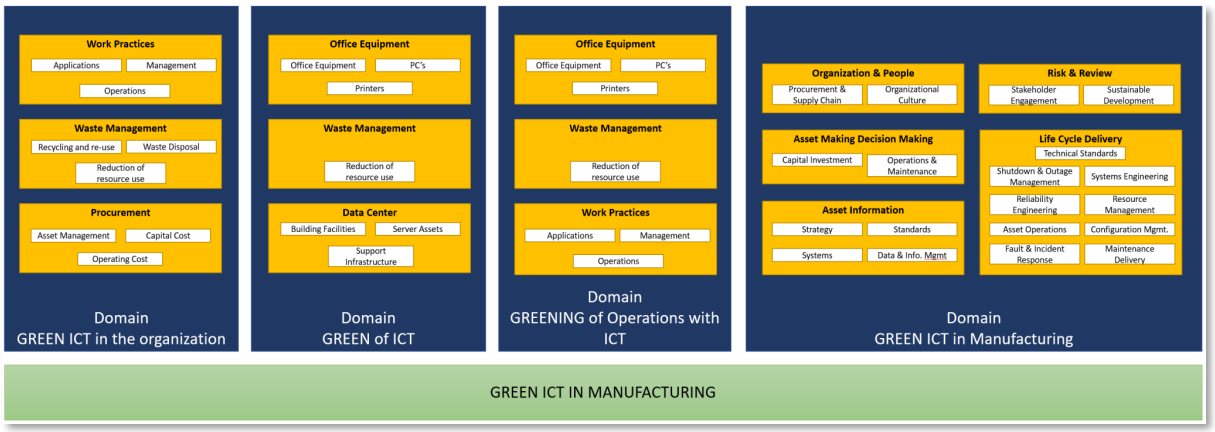

Figure 12: Green ICT maturity framework for manufacturing (GITMM-MANU)

A high-resolution version of this framework is available (see Figure 21). The detailed maturity GITMM-MANU including all the components and supporting questions is available in Table 28. To

clearly identify the source of the component, Table 28 contains specific font settings as defined below:

- Components derived from Hankel are **underlined** in blue.
- Components derived from Sang-Huyn are regular script.
- Components inspired by IAM and defined by researcher are ***italics*** in green.

The components and questions defined by the researcher are inspired by the IAM subjects, combined with the researcher's extensive experience in the manufacturing industry.

3.4. The objective of the follow-up research

With the Green ICT model for manufacturing (GITMM-MANU) completed, the remaining research is focused on the validation of the proposed model. The objective for the empirical research can be summarized as the following:

Verification of the theoretical model to measure Green ICT maturity for the manufacturing industry. The goal of the model is to be used independently and produce consistently reliable results that can be used by an organization.

To achieve the objective of the next phase, the empirical phase is designed to answer multiple main and sub-questions. These questions are listed in Table 10. Based on these empirical questions, chapter four will detail how the research will be conducted.

Table 10: Empirical research questions

ID	Research Sub Question	How and where will the information be collected?	Why is this information relevant?
E1 - Is the presented model valid for the manufacturing industry?			
E1.1	Are the domain definitions, complete and valid for the intended purpose?	Through discussion as part of the semi-structured interviews	The presented domains provide the framework. It is important to have these core elements in the framework confirmed for completeness.
E1.2	Are the attribute definitions, complete and valid for the intended purpose?		The attributes describe across the domains, different areas for Green ICT for a manufacturing company. It is important to validate the completeness of the attributes.
E1.3	Are the component definitions with the supporting questions, complete and appropriate for the intended use?		This question will provide input on the quality of the components which is important for the verification of the model.
E1.4	Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?		Each component is provided with a clarifying question to support the respondent. These clarifications need to be correct to support the respondent.
E1.5	Are there any components specifically for manufacturing missing from the model?		The model needs to be complete for it to be relevant for the industry.

ID	Research Sub Question	How and where will the information be collected?	Why is this information relevant?
E1.6	Are the selected respondents, the most appropriate individuals for completing the assessment?		For the best outcome, the most appropriate individual needs to participate.
E1.7	Are there components that are in the year 2020, not relevant or accurate for the model?		This will provide an indication if the model is up to date and measures Relevant components.
E2 – Is the model producing results that can be used for its intended purpose?			
E2.1	Is an organization able to measure and define improvements based on the proposed model?	Through discussion as part of the semi-structured interviews	The output of the model needs to support an organization in determining the next steps. Understanding to what level the model does this is important for the practical use of the model.
E2.2	Is the developed model easy to use for the intended respondents?	Through discussion as part of the semi-structured interviews	The model needs to be practical, clear and concise to prevent over usage of the respondent's time and commitment.
E2.3	Does the model provide a complete and easy to understand a picture of the maturity of Green ICT within the organization?	Through discussion as part of the semi-structured interviews By analysing the completed assessments from the respondents	The output of the model should provide the respondent with a complete picture of the Green ICT maturity level.
E3.4	Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?	Through discussion as part of the semi-structured interviews	The output of the model needs to support the organization with defining improvement steps, this is an indicator of the quality of the model.
E3 – What is the maturity of Green ICT for the measured organizations?			
E3.1	What is the maturity of organization 1?	Through collection of the completed assessments provided by the respondents.	Measuring the organizations provides insights into their maturity. Different reports can provide insights into the weaker and stronger areas and how the measurements compare to the factors of influence.
E3.2	What is the maturity of organization 2?		
E3.2	What is the maturity of organization 3?		

4. Research methodology

The third chapter provided the input required to develop a theoretical model for Green ICT for industrial manufacturing. This chapter 4 will design how the theoretical GITMM-MANU will be validated as part of the empirical research; this is the demonstration step in the DSRM approach. The DSRM method is geared towards the development of complex information management models and describes the methods and procedures required, see Table 2 (Peffers et al., 2007).

4.1. Conceptual design: select the research method(s)

During the empirical phase of this project, the goal is to validate the theory against a real-life setting. Designing a research method is like peeling away an onion of layers that each provides a different point of view on the research, its intended outcome, limitations, philosophy, etc. Each layer presents the researcher with different options. Combined they will act as a compass for research design (Saunders et al., 2016, p. 164). See Figure 13 for a description of the methods used for this research and choices available.

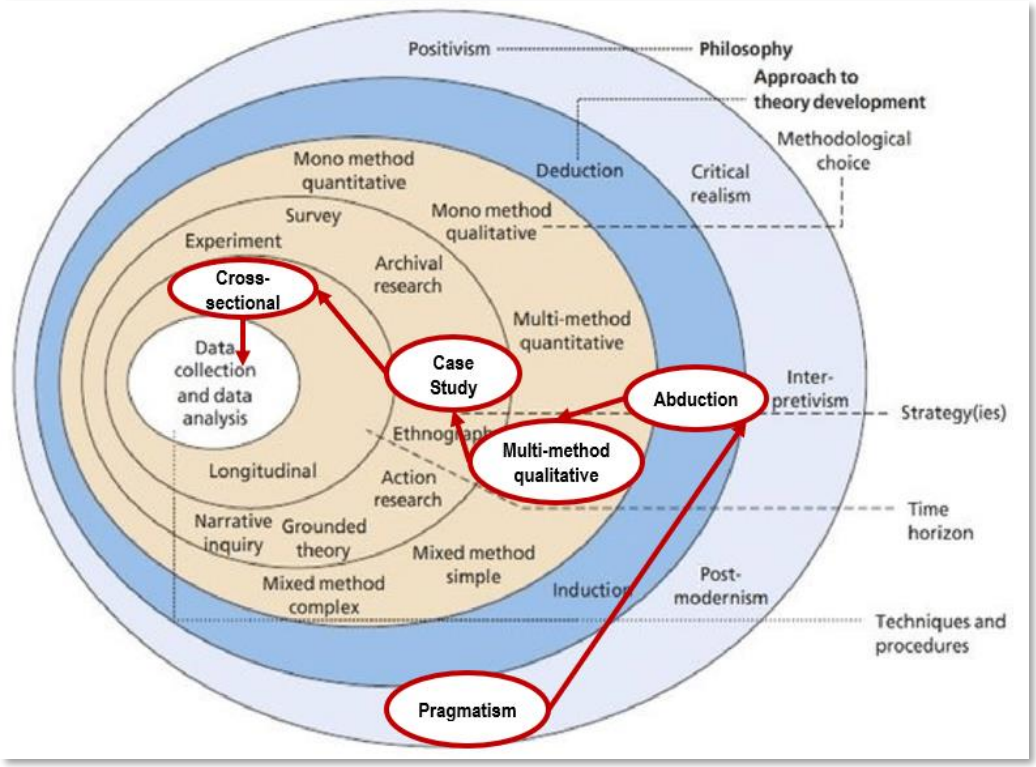

Figure 13: Research methods layers (Saunders et al., 2016, p. 164)

The philosophy layer describes how the researcher sees the world around him. This research has a **pragmatism** approach as it is addressing the problem of developing a Green ICT maturity model for manufacturing. The development of the GITMM-MANU leads to practical usable value for academics and industrial manufacturing.

The approach to theory development taken was **abduction**, as the researcher has stated the perceived lack of a Green ICT maturity models for manufacturing. This theory was evaluated through a critical review of the existing literature to then propose a suitable model. The new or adjusted theory was created by examining the underlying constructs of Green ICT, maturity, existing Green ICT maturity models, and manufacturing processes.

The selected methodology is a **multi-method qualitative** approach. Representatives from the selected companies will be asked to complete the maturity GITMM-MANU for their situation through a simple Excel work sheet. Upon completion, a follow-up semi-structured interview will be scheduled to further address the research questions and review the outcome.

The applied strategy will be a **multiple case study**. Case studies support the in-depth understanding of a topic or phenomenon in its real-life setting. (Saunders et al., 2016, p. 187). The reason for a multiple case study is to find strong evidence for replication of the proposed GITMM-MANU. A single holistic case study would only provide input from a single organization driven by its values, processes, and strategies.

Due to the limitations in time for this research, the time horizon will be **cross-sectional.** The limitation of time introduces the fact that only a single measurement across the different organizations can take place.

The **data collection** methods will be a combination of the completed GITMM-MANU by the respondents, the input gathered as part of semi-structured interviews, and secondary data in the form of documentation publicly available such as corporate responsibility reports.

4.2. Technical design: elaboration of the method

The technical design provides details for how exactly the data will be collected. Secondly, the detailed design will elaborate on the reason why we need this data to answer the empirical questions.

For each participating organization, the goal is to interview two individuals. One of the respondents will represent the ICT organization for the company, the second respondent will represent the engineering area for the company, who will be able to provide detailed feedback on the manufacturing domain in the GITMM-MANU. Many of the organizations in this industry are organized, where an individual plant has a high level of autonomy. Many plants have their own ICT systems, their own engineering departments, their own operations team and so forth. The following criteria are in place for the respondents:

- The respondent has been with the company for at least 1 year to allow for enough insights.
- The respondent has a college degree or equivalent work experience.
- The respondent is aware of the sustainability efforts of the company.
- The respondent is either on the ICT side for input from the ICT organization (domains 1 through 3) or works for the engineering department for the organization for input (domain 4).
- The respondent is ideally at a managerial level.
- The role of the respondent is one of the following or equivalent: ICT manager, Application manager, Engineering manager, operations manager.
- The respondent works at a plant location in the U.S.

The researcher utilized his own network to connect with individuals that are a good fit for the interview. Upon agreement to cooperate, the following steps will take place.

1. **Introduction:** the researcher provides an email with the documentation on the topic, the goals and how this is beneficial for both the respondent and the researcher. The email will explain next steps to help prepare and set reasonable time limits for participation. The following information will be shared with the respondent:

    a. An introduction to the research (see Appendix 15 – Respondent presentation introduction)
    b. The developed GITMM-MANU in the form of a spreadsheet
    c. The interview questions for the follow-up interview

    A template for the communication with the respondent is available (see Appendix 13 – Respondent communication for participation).
2. **Complete Green ICT maturity assessment:** The respondent is expected to complete the assessment within a reasonable time (1 to 2 weeks) and prepare for the interview. The completed GITMM-MANU (see Table 28) has been translated to an easy to use excel format (the assessment) that can be used by the respondents.
3. **Semi structured follow-up interview**: The purpose of the interview is to review the proposed GITMM-MANU in terms of applicability and practical use. The interview questions are available in Table 29. The interviews will be recorded. The first interview will be used as a test-case to verify the set time constraints as well as ensuring the questions are clear and can be answered by the respondent. The test-case will be transcribed to verify the method of data capture and analysis with the mentor from the OU. If required, subsequent interviews will be transcribed to support the quality of the data analysis.
4. **Interview verification**: After the interview is completed, a summary of the interview will be created and sent for review by the respondent.
5. **Data analysis**: The results of the interviews and assessments will be anonymized for inclusion in the research report. The research results will describe in general terms the role and experience of the respondent.
6. **Handling of interview data**: The recordings will be verified by the mentor from the OU and destroyed upon completion of the research. Interview summaries will be anonymized and included as an appendix for this report.

Upon completion of the research, respondents will receive a copy of this report.

4.3. Data analysis

Based on all the available information, a qualitative method will be used to analyse the data. First a spreadsheet will be used to summarize the results of the interviews. On the Y-axis, all the interview questions will be placed, where the X-axis will show all the answers summarized. Additional themes discovered throughout the interview will be analysed through a second spreadsheet. On the Y-axis on the second spreadsheet, the various recurring themes will be listed, where the X-axis will show the different responses for this theme. Through this approach similar patterns will emerge (Saunders et al., 2016, p. 579).

Thematic analysis is a generic approach for analysing qualitative data. Amongst many advantages for this approach, an important one, the approach is less dependent on the research philosophy. Amongst the downsides compared to a quantitative approach, the outcome is dependent on the researcher's interpretation. It is important to record researchers assumptions and be as explicit as possible (Saunders et al., 2016, p. 579).

The completed maturity assessments will be available for archival purposes in an anonymized format. The results will be presented through various diagrams to state the maturity of the individual organizations and across organizations. Maturity scores will be averaged per organization, attribute and across organizations. The average is not based on a weighted average (Saunders et al., 2016, p. 528).

To summarize, the steps in Figure 14 will be performed to answer the research questions. The transcription step will be used as applicable.

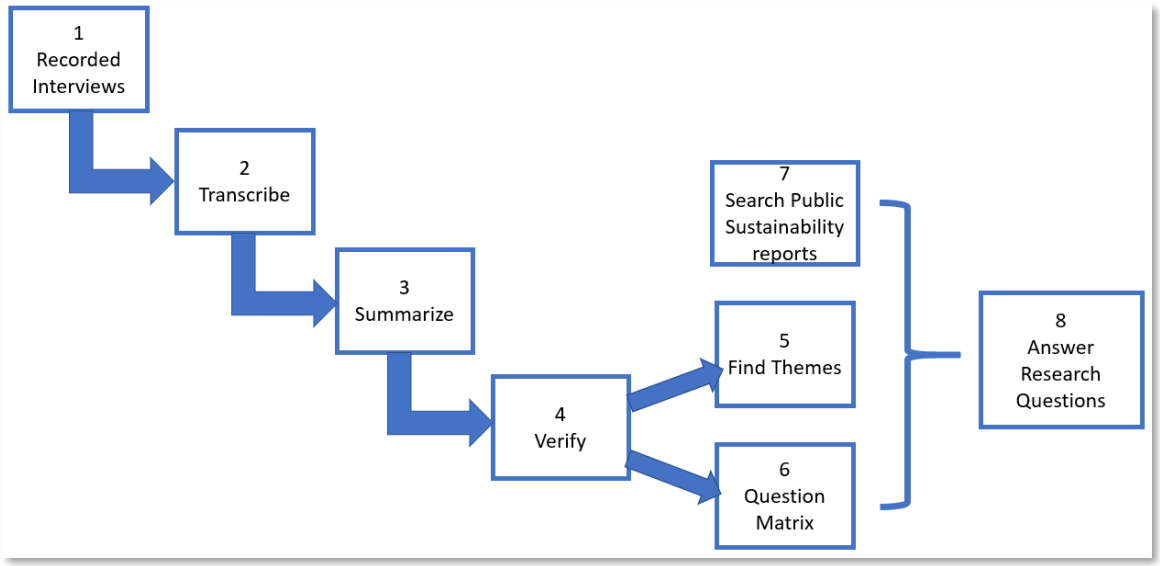

Figure 14: Interview analysis steps

4.4. Reflection concerning validity, reliability, and ethical aspects

The goal of research is to contribute to the body of knowledge and add practical value. Research needs to be conducted in a valid, reliable, and ethical manner. It needs to be possible to verify the results and replicate the research with the same outcome. The researcher needs to conduct himself according to ethical norms.

4.4.1. Validity

Validity has three points of view to address if the information gathered is the correct information (construct validity), how conclusions are reached and if these are the correct conclusions (internal validity), and if these conclusions are applicable to similar cases outside of the research (external validity).

Construct validity

The following measures will be taken by the researcher to ensure the correct information is gathered:

- The results of the data analysis will be corroborated by utilizing documentation publicly available to triangulate the results.
- The summary of the interview will be sent for verification with the respondent.
- The respondent needs to be an expert in the field of ICT or be an expert in engineering/operations for a process manufacturing company.
- Respondent bias – the results of the interview are compared with the input available in the company's documentation as provided and publicly available.
- The interview questions will be shared beforehand, for the respondent to prepare and ask any questions as needed.

Internal validity

Internal validity addresses concerns around how the conclusions are reached and if the conclusions truly reflect the real-life setting. The following measures will be taken to address this:

- The data analysis follows the procedures and guidelines as recommended for thematic analysis (Saunders et al., 2016, p. 579).
- The research design aims to review the GITMM-MANU with 3 different companies to confirm validity.
- By applying negative case analysis, the researcher will discuss samples, patterns, and themes that do not support the conclusions drawn from the data analysis.
- A detailed description of the respondents will be used to build validity in terms of their experience as subject matter experts.

External validity

The external validity of the research describes to what extent the results of this study can be generalized for other similar cases. The nature of the study is to define a new Green ICT maturity model for industrial manufacturing. Based on the aim to utilize three companies to participate in the research, the researcher has selected **literal replication** by selecting companies that are very similar.

4.4.2. Reliability

The reliability aspects of the research deal with concerns to ensure that a different researcher would achieve the same outcome. Providing detailed instructions on how the research was conducted, and how conclusions were reached are critical to ensure a reliable outcome. As part of the data collection, the researcher will minimize the impact of subjectivity, by formulating questions that are clear and are not ambiguous. The literature study, and empirical research, are carefully documented to ensure other researchers can replicate the same study.

4.4.3. Ethical aspects

Research needs to be performed in an ethical manner. The researcher works for a consulting firm specializing in services for industrial manufacturing organizations. There will not be any sort of hierarchal relationship between researcher and respondents. Summarizing the various aspects of ethical research, Table 11 describes the different aspects which will be followed with respect to ethical manners.

Table 11: Ethical Research Aspects

Ethical principle (Saunders et al., 2016, p. 243)	**Rationale for this research**
Integrity and objectivity of the researcher	The researcher will act openly, be truthful and promote accuracy. No deception, partiality, deception or promises will be made, and conflicts of interest will be declared.
Respect for others	The rights of the respondents will be recognized. Responsibilities to those that take part will be recognized. The respondent will have the right to absence of coercion.
Avoidance of harm	Any harm to respondents will be avoided – the respondents will not be embarrassed, discriminated, cause stress or put in a conflict situation.
Privacy of those taking part	Privacy underpins all ethical principles. The respondent, and the organization's privacy will always be ensured. The respondent will be informed that the interviews are recorded, and has the option to decline the recording. Results published will be anonymized.

Voluntary nature of participation and right to withdraw	Respondents will not be forced or harassed into participating. Even if participating voluntary, the respondent has the right to withdraw and/or not respond to specific questions.
Informed consent of those taking part	The respondent will understand the implications of participation (time commitment, recorded information) so he/she can reach an informed decision about whether to participate.
Ensuring the confidentiality of data and maintenance of anonymity of those taking part	Respondents and the organization will be anonymous. Confidentiality will be respected strictly. The intent is to keep the respondents, respondent's company, and the respondent's results anonymous in the thesis report. Any confidential information as applicable will be available to the thesis evaluation team at the Open Universiteit Nederland.
Responsibility in the analysis of data and reporting of findings	Privacy, anonymity, and confidentiality will be upheld when reporting data. Findings should be reported fully and accurately, even if they contradict expected outcomes. Interpretations of the results should be checked carefully. The organization and respondents have a right to quality research and will be debriefed if requested.
Compliance in the management of data	No personal data will be captured. Legal restrictions and regulations related to the management of research data will be complied with.
Ensuring the safety of the researcher	The risk of physical threat or being in a compromising situation will be assessed and avoided.

5. Empirical Results

This chapter describes the results of the research. The research methodology as explained in the previous chapter is used to execute the empirical phase.

5.1. Interview and data analysis execution

The execution of the empirical research has followed the steps as explained from the research design. Several differences are in place and the planned steps and actual steps are listed in Table 12.

Table 12: Planned and executed research steps

Design	Planned step	Executed step
Selection of respondents	The plan was to select 2 individuals per organization with multiple criteria for each respondent.	***Deviation:*** Interviews took place with 1 individual per organization One individual worked for ICT. Three individuals worked for engineering / operations. One individual works in The Netherlands Three individuals work in the U.S.
Selection of 3 similar organizations	The plan was to select 3 similar organizations active in chemical processing	***Deviation:*** The interview took place with 4 organizations active in manufacturing. 2 Chemical process companies (USA and NL) 1 Oil & Gas company (U.S.) 1 Power company (U.S.)
Qualified respondents	Respondents needed to be qualified for the interview and living in the U.S.	***Deviation:*** One respondent was from The Netherlands. All other requirements have been met
Respondents work at a plant location	All respondents needed to work at a physical plant location	***Deviation:*** 2 of the individuals worked in a corporate function, but previously held plant location functions. 2 other individuals worked at a specific plant.
Utilize researchers' network	Utilize the researcher's network	***Deviation:*** Researcher's network as well as network from fellow students and the OU where used to find respondents.
Use pre-defined communication methods	Communicate through pre-established protocol and information	Executed as planned, Appendix 13, 14, 15.
Completion of the assessment	All respondents to complete the assessment prior to the interview.	Executed as planned
Semi-structured interviews	All respondents to be interviewed in a semi-structured method.	Executed as planned
Interview recording	Create a recording for all the interviews	Executed as planned

Design	Planned step	Executed step
Interview transcription / summary	Create a transcription as applicable and summary for all interviews	Executed as planned, Appendix 16
Interview verification	Verify the interview with every respondent.	Executed as planned
Anonymized results	Ensure results are anonymized	Executed as planned,
Corroborate with public information	Review publicly available information	Executed as planned, Appendix 17
Thematic analysis	Analyze the interview results through thematic analysis	Executed as planned, Appendix 17, 18
Averaged maturity scores	Provide several graphs that display maturity levels	Executed as planned, Appendix 19
Respondent description	Provide a short description of the respondent, his experience and relevance for this research	Executed as planned, Appendix 17
Ethical aspects	Perform the research in an ethical manner	Executed as planned

The interviews have been conducted between the timeframe of February 11, and March 8, 2020. Potential respondents were approached starting the last third week of January 2020, after verbal approval of the research preparation work by the OU (course IM0602). With initial preliminary responses being positive, researcher did not approach additional individuals. When the actual participation was requested, from the initial group of individuals, several declined or were not able to get a hold of the person responsible for ICT within the organization. At this point (mid-February), researcher started asking additional individuals from his network, and received support from other students as well as the mentor from the OU. As time progressed, it became increasingly more difficult to receive confirmation to participate because of the unfolding COVID-19 global pandemic. With time running out, the decision was made to restrict the research to the four interviews.

5.2. Empirical research questions

5.2.1. Presentation of the results

This chapter will present the results of the interviews and assessments. Before providing a more detailed presentation per the research questions, the high-level results are displayed below. The first result is the matrix that describes the research questions and the answers from the respondents. An overview of this matrix is displayed in Table 13, for which a high-resolution version is available in Table 32. The results of this matrix are based on the interview summaries available in Appendix 16 – Interview results. The text marked yellow in Appendix 16, provided the input to answer the interview questions presented in Table 13.

Table 13: Research questions results matrix

Research Question	Research sub question / topic	Interview 01	Interview 02	Interview 03	Interview 04
Generic	**Respondent location**	*USA*	*USA*	*USA*	*NL*
	Type of organization	*Power generating utility, state regulated*	*Chemical Manufacturing*	*Oil & Gas Exploration and Production*	*Chemical Manufacturing*
	Role in the organization	*Engineering manager*	*Engineering Systems Manager*	*Digital Information Manager*	*Shift Manager*
	Prepared for the interview - read the introduction and questions and completed the assessment	*Yes*	*Yes*	*Yes*	*Partially, did not read the questions*
E1 - Is the presented model valid for the manufacturing industry?	**E1.1 - Are the domain definitions, complete and valid for the intended purpose?**	*Yes*	*Confusing, rename domain 4 to facility operations*	*Very applicable, although manufacturing is relevant - but a little bit less perhaps compared to chemicals or refining for an E&P organization.*	*Yes, but separation of policy and strategy specific attributes and components would improve the model*
	E1.2 - Are the attribute definitions, complete and valid for the intended purpose?	*Yes*	*Yes, adequate for this type of assessment*	*No real attention, but nothing seemed missing*	*Yes - respondent did not pay much attention to the attributes, but are complete and valid upon review with interviewer*
	E1.3 - Are the component definitions with the supporting questions, complete and appropriate for its intended use?	*Thorough, not burdensome or repetitive*	*yes, concise, focused, well communicated*	*Yes, appropriate and clear* *Some questions did not apply. Option for maturity rating*	*Questions are easy to understand, for the questions he could answer as part of his role.*
	E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?	*Yes, Good method*	*yes, not overly complicated or difficult to answer based on the scale - additional samples could help*	*yes, easy to use and enough for the purpose* *some don't apply for an E&P business*	*Scale was easy to use, but some components did not apply or outside of the respondents knowledge, having an option to indicate that would be helpful.*
	E1.5 - Are there any components specifically for manufacturing missing from the model?	*No, Very comprehensive*	*No, not for this assessment and the intent and purpose*	*no, level and complexity are appropriate*	*Several topics were raised for new or additional attention, wastewater, optimized communication with regulatory bodies and finally management of change processes.*
	E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?	*people are most appropriate, include lower level positions for input on how things are in practice*	*Also invite manufacturing operations and super intendents to achieve practical insights*	*Yes, but important to retrieve feedback from specialists as applicable*	*Assessment covers a wide array of topics that would require input from different individuals (specialists)*
	E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?	*No*	*No, some questions are more progressive than where the company currently is.*	*No components not relevant or accurate*	*The components were accurate and relevant for the organization.*
E2 – Is the model producing results that can be used for its intended purpose?	**E2.1 - Is an organization able to measure and define improvements based on the proposed model?**	*maybe, good to start conversations, specialist support needed to define actions, tune for specific organization*	*Maybe, good reflection of current state*	*Yes, with the support from experts*	*The model will create awareness on the topic, but to improve a more detailed analysis will be required.*
	E2.2 - Is the developed model easy to use for the intended respondents?	*yes, easy to use,*	*Yes, easy to use and usable results*	*Yes, easy to use for the intended individuals*	*The model itself is easy to use and provides an initial overview*
	E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?	*Charts good starting point*	*Maybe, sustainability for manufacturing company has many different points of view, proper scope is required at the start*	*Yes, provides a good high level picture, which are in line with the expected outcome.*	*From the ICT point of view, respondent is not able to answer, from a Manufacturing point of view, the presented picture is accurate.*
	E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?	*Define initial roadmap, consulting required for actual roadmap and definition of impact*	*Model provides good initial insights through different graphs*	*Yes, it depends a bit on the domain and Manufacturing domain will require additional expertise*	*To implement improvements, more details would be required from a manufacturing point of view.*

The second result is the results of the thematic analysis based on the results of the interview questions. This is displayed in Table 14, for which a high-resolution version is available in Table 33. Table 14 is based on the interview summaries, where the text is marked in ***bold italics.*** Based on the marked text, the researcher organized similar answers and grouped these in the themes as displayed. The results of this will be discussed in chapter 6.

Table 14: Thematic analysis results

Themes / Source	Interview 1	Interview 2	Interview 3	Interview 4
Invest in Green	100% Renewable Energy, state mandated, fairly recent	recent creation of high-level sustainability position Value of green for the organization?	Recent (months ago)appointment of Senior Vice President responsible for ESG (environmental, safety, governance)	Company has an active sustainability program and aligned its goals with the UN SDG's
High-level assessment	first assessment	First assessment to start discussion, more detailed topics specific to Manufacturing can be applicable	Initial assessment to then refine for more details	Initial assessment, to define a more detailed assessment
Impact of actions	Determine domain most impact How impact people, planet, profit	What is the impact for working on specific aspects?	Senior management will want to understand the impact and how to move forward.	
Green Awareness	Invite larger group to create awareness Understand how things are affected		Attributes created awareness on topics he did not know were important.	Outcome of the assessment will create awareness, which is a big challenge for the organization.
Elaborated components	Elaborate method - more questions and examples, later stage	additional samples to guide the user with the maturity scale		adding small samples to guide the user but balanced with the time to needed
Sustainable performance	We want to be more sustainable, but not sure where to start.		How to benchmark against others will drive the discussion	Driven by cost, but explained as green initiatives.
High area's of impact for manufacturing organization		Logistics High Carbon footprint	Level of adoption of good modern collaboration technology	Highest impact is improvement in the manufacturing process.
Policy, Procedures	Actively implementing green in policies			Green strategy and policy needs to be set by management
Organization specific	Tune to organization terminology		Verify applicability of the questions for the specifics of the business.	
Assessment project		Include proper resources for actual assessment More detailed scope and definition	Respondent connected with different specialists Define well organized project with PM, sponsor, central contact	
Fragmented Organization	Organization feels very segmented IT and Power generation operate in silo's			
Culture	Culture shaped by policies, but requires leading by example			

The third result is the measurement of maturity for the organizations. These results are displayed in Figure 15, for which a high-resolution version is available in Figure 27. The attributes are ranked low to high within the domain to visualize stronger and weaker areas. Appendix 19 – Green ICT maturity level for interviewed organizations, also show the average measurements per organization.

Figure 15: Average maturity across organizations

As part of the analysis phase, sections from the interview have been highlighted yellow to define the question matrix. For the theme analysis, sections from the interview have been marked as ***bold italic*** to indicate they have been used for the themes (see Appendix 16 – Interview results). The combination of establishing the matrices, combined with the public information provide the input to answer the questions E1 and E2.

With an understanding of the high-level results, and how both the matrices have been established, let us review the research questions in more detail.

5.2.2. E1 - Is the presented model valid for the manufacturing industry?

E1.1 - Are the domain definitions, complete and valid for the intended purpose?

The answer is mostly yes, but two specific recommendations where made based on the interviews. The first one is to rename the fourth domain to “Facility Operations”. The second recommendation is to introduce a domain specific for policy and strategy.

E1.2 - Are the attribute definitions, complete and valid for the intended purpose?

None of the respondents paid a lot of attention towards the attribute definitions. During the interviews, researcher asked respondents to quickly review the attributes. All respondents confirmed that nothing was missing, and the defined attributes seemed logical and valid. Since respondents only did a quick pass of the attributes, this is weak in terms of internal validity.

E1.3 - Are the component definitions with the supporting questions, complete and appropriate for the intended use?
All respondents confirmed that the components were complete, and appropriate for the intended use. Feedback received was that the questions were thorough, not burdensome, not repetitive, clear, concise, focused, well communicated, and easy to understand.

E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?
All respondents agreed that the scale was easy to use for the components and questions. Three comments were made to this effect. The first one was for additional supporting language to support the questions being asked, such as sample answers. The second was to include a scale level that represents "Outside of my expertise". The third level was the ability to rate something as "does not apply".

E1.5 - Are there any components specifically for manufacturing missing from the model?
Three respondents agreed that the specific manufacturing components where complete and appropriate. A fourth respondent recommended to review additional topics such as: management of change, waste-water management, and communication with regulatory bodies.

E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?
All respondents agreed that the targeted individuals are a good starting point. All of them also agreed that receiving additional input from specialists across the organization is required for a more accurate response on the assessment.

E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?
All respondents agreed that that components were relevant and accurate considering the year 2020 and current state of technology. One respondent provided the feedback of several questions being much more progressive than their current organization was thinking of.

5.2.3. E2 – Is the model producing results that can be used for its intended purpose?

E2.1 - Is an organization able to measure and define improvements based on the proposed model?
Respondents agreed that the assessment is a good starting point and provides a good initial reflection of the current state. Two additional comments were made. The first comment is that it will take a specialist in the specific manufacturing area to define an actual improvement program. As an example, to introduce 'smart motors', the types of smart motors that can be used is depending on the type of manufacturing and regulations. An electrical substation for a power utility is different from a highly volatile chemical environment. It would be good to tune the assessment towards the type of manufacturing for this reason.

E2.2 - Is the developed model easy to use for the intended respondents?
All respondents agree that the model is easy to use, and the results are easy to interpret.

E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?
Respondents again agree that this is a good starting point. One of the respondents provided the input to clearly define the scope upon the start of the assessment. This assessment has a very

specific scope for manufacturing operations and as an example does not include logistics or supply chain currently. It is important to align expectations around the outcome of the assessment.

E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?

All respondents describe how a detailed roadmap will be difficult to establish for the manufacturing side. Specialized engineers with detailed knowledge about the manufacturing process will need to support the roadmap development to determine if specific applications are possible and will generate the intended outcome.

5.2.4. E3 – What is the maturity of Green ICT for the measured organizations?

The last research question (E3) was to display the measured maturity of the interviewed organizations. In chapter 4.3 the researcher explained the plan was to display the results of the assessments through different presentations showing averages. Figure 16 below shows the average maturity score for each organization per the domain. From this initial figure, several notable differences are visible that will be discussed in chapter 6. See Figure 26 for a high-resolution version.

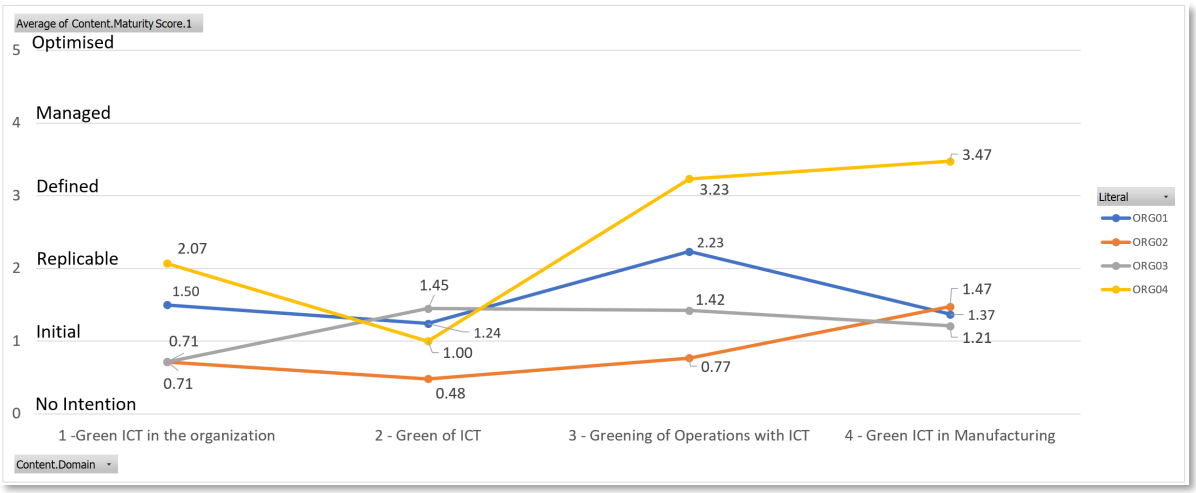

Figure 16: Average Maturity per domain and organization

While the average maturity for the interviewed organizations is displayed in Figure 16, it is equally important to look at the overall picture. In Figure 15, the combined averages for all organizations are displayed as well as the average ratings per attribute. See Figure 27 for a high-resolution version of this graphic. Chapter 6 will discuss these results in more detail.

6. Discussion, conclusions, and recommendations

Chapter 5 is a presentation of the research results. Chapter 6 will form an opinion of these results combined with conclusions, recommendations, and a reflection on the overall research.

6.1. Discussion

The discussion of the research results follows the original research questions, and the additional details as discovered through the analysis. In addition, we have reviewed public information from the participating companies per the technical design from chapter 4.2 (see Table 31).

Research Question: E1 - Is the presented model valid for the manufacturing industry?
Based on the input from participating organizations, the model is covering the right topics for the manufacturing industry at a high-level. The interviews brought to light that the use and opportunities for Green ICT as part of the office environment (domains 1 through 3) is extremely small compared to the opportunities presented and discussed in domain four (Green ICT in manufacturing). See interview 04, opening words. This result is not a major surprise, the GeSI report predicted major opportunities for smart manufacturing applications with a CO_2 abatement opportunity of up to 22% compared to for example E-Work offering just 3% (Global e-Sustainability Initiative, 2015, p. 18).

The question then remains if a GITMM-MANU as developed should be more focused on the manufacturing domain. Based on a review of the different themes (Appendix 18 – Themes analysis results matrix) the researcher argues that the GITMM-MANU still has a lot of value as a high-level tool. The themes revealed overlapping areas of interest such as general awareness in the organization, policy making, culture, and sustainable performance. Two of the respondents vividly described that on one side, policy and strategy needs to be set by higher management to incorporate Green, but at the same time, the people working at the facility carry the tone and culture of the organization in terms of sustainability. Three of the respondents also described the importance to rate themselves against similar companies as a force to drive sustainability efforts. A maturity model specifically focused on the technical areas of manufacturing would potentially exclude these cross departmental interests and wider adoption.

In terms of the manufacturing specific components (domain four), all respondents agreed it carried the right level of complexity to spur discussion and research. Translating the results of domain 4 to actions will require specialists. As an example, to utilize smart motors – the type of smart motors depends on the environment they are being used in. A highly volatile chemical environment is bound to different regulations, compared to an electrical substation.

With the research originally aiming at process manufacturing, the respondents all worked for slightly different manufacturing companies (Chemical, Oil & Gas, Power Utility). All agreed that the GITMM-MANU seems to be a good fit for companies that own and operate large complex machinery in a mass production type setting, which is not necessarily limited to just process manufacturing.

Research Question: E2 – Is the model producing results that can be used for its intended purpose?
Based on the feedback, all respondents described that the results of the assessment felt accurate for their level of maturity. With the intent to spur further discussion, research, and high-level roadmap development it accomplishes this goal. Like the discussion for the first question E1, it is important to understand the complexity of the manufacturing space. Although this GITMM-MANU included a specific domain with a focus on manufacturing, one respondent highlighted how supply chain for

manufacturing has a large influence on their path to green. To accommodate their customers, they utilize many different forms of transportation (boats, barges, railroad, road transport, etc). Finding a good mix of these capabilities has been challenging. The GeSI report points out a potential CO_{2e} abatement of up to 10% (Global e-Sustainability Initiative, 2015, p. 18) for smart logistics.

Whilst logistics was considered out of scope, it brings to light the need to properly set the scope, expectations, and outcome what this version of the assessment will provide when utilized for an organization.

Research Question: E3 – What is the maturity of Green ICT for the measured organizations?
Based on the data gathered, several discussion topics are raised. These topics are presented below.

Average maturity across organizations
In Figure 27, we have displayed the averages across the four organizations. At the level "initial", the maturity level for organizations is low. This seems correct when three of four organizations claimed to have just recently started to pay more attention to the topic of sustainability.

Regional differences
Based on the combined results from Figure 16, we see that the results from organization 04 (yellow) are significantly higher compared to the others. Organizations 01 to 03 are based in the U.S. Organization 04 is from The Netherlands. The KPMG report paints a similar picture, stating that the U.S. region performs poor in terms of translating their sustainability to actual SDG goals (Blasco & King, 2017, p. 42). We need to be critical since this is just a single measurement and SDG's are not necessarily the same as maturity. It remains an interesting observation that could spur more research.

Other observations

Internal corporate communication
Three of the respondents described how their organization recently started with sustainability initiatives and how timely this interview was. Based on the public information, all four organizations have been reporting on sustainability for at least the last five years. Based on the different public reports, there are notable differences, but probably more important is the apparent lack of internal communication.

Factors of influence
In Table 24, every component of the GITMM-MANU has been linked to a factor of influence and the associated type of impact. This allows for a presentation of the GITMM-MANU, per domain and the maturity for a specific type of impact (see Figure 17). Several interesting elements are shown that are shortly discussed below.

Except for the second domain, all domains have the highest maturity through indirect impacts. In other words, the use of ICT applications scores highest.

The third domain – green of the operation – has an outlier with a very low score for organizational impact. Strategy, policies, and other organizational influences apparently do not drive the greening of the operation. One explanation could be that operational efficiencies driven by new technologies are a bigger driver, compared to the driver to green the operation. This would need to be further investigated.

For the fourth domain a similar picture is presented. It is somewhat of a surprise that societal impact scores relatively low. Given the major risks for the industry it would have been expected that this would have a higher maturity. This again is a topic of potential research to better understand how manufacturing organizations are influenced to invest in greener operations or if financial drivers are more prominent. The graphic is not displaying systematic effects. These are not represented in the GITMM-MANU as described in 3.3.3.

A high-resolution version of this figure is also available in Figure 28.

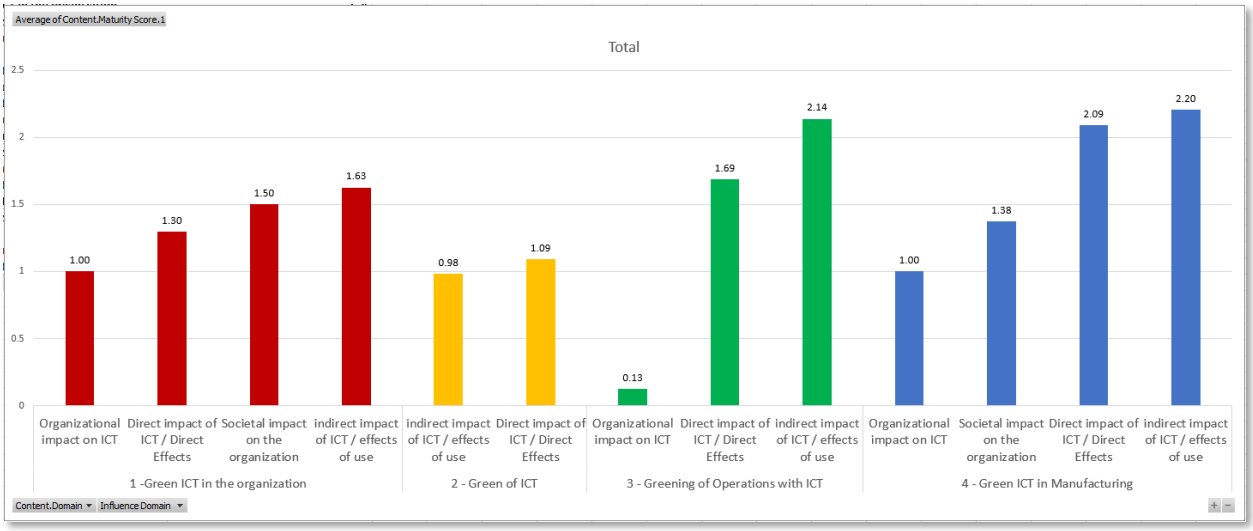

Figure 17: Type of impact maturity per domain for GITMM-MANU

Discovered themes from the interviews

Based on the interviews, several themes emerged that can guide further discussion of this topic. Some of the themes are overlapping with the research questions, or not all the respondents provided feedback on this theme. The themes below are selected because they have not been discussed elsewhere and made the most impact on the researcher.

- **Invest in Green – commitment and communication (4 respondents)**
  All respondents confirmed their organizations commitment towards sustainability. The level of commitment and how organizations report is very different from one organization to the next. As stated earlier, there seems to be a general awareness challenge in how organizations internally and externally communicate and promote their sustainability activity.

- **Impact of actions – what do we gain? (3 respondents)**
  This theme is related to how organizations internally struggle to promote and execute on green initiatives. Three of the respondents all described how senior management would very quickly ask, what the impact will be in terms of cost and benefit, and to a lesser degree to look at all three aspects such as People, Planet and Profit (one respondent). Where green programs are still in an infancy phase, the uncertainty about the organizational benefits clearly hampers the execution and wider adoption of thinking green.

- **Sustainable performance – How do others perform? (3 respondents)**

Two of the respondents from the USA described how it would be very beneficial to benchmark their organization to comparable organizations. The U.S. has a competitive culture, it would be interesting to explore how benchmarking could be used to improve the overall awareness.

6.2. Conclusions

Different points of view have been discussed and presented in chapter 6.1. The conclusions summarize for each of the research questions what the conclusion of the research is.

E1 - Is the presented model valid for the manufacturing industry?
The GITMM-MANU is a good representation for the manufacturing industry as a first version. Several conclusions are drawn based on the expert input through the interview. These conclusions are listed below:

- The name for the fourth domain: "Domain Green ICT in Manufacturing" should be replaced with "Domain Green ICT in Facility Operations".
- Future versions should introduce a fifth domain that has a strict focus on strategy and policy for the organization.
- For a future version, additional components should be added to cover the topics of waste-water, management of change, and regulatory communication.
- For a future version, a consideration should be made to include auxiliary manufacturing processes such as logistics.

E2 – Is the model producing results that can be used for its intended purpose?
The answer to this research question depends on the point of view. The answer is yes for in that the presented results are an accurate representation. The GITMM-MANU provides insights into topics of the four domains. For the first three domains, the results are detailed enough to define a roadmap for improvements. For the fourth domain, all respondents described the assessment to be accurate and up to date, but also as high-level for the manufacturing environment. As such, the results can be used to guide a high-level discussion and direction, but expert input would be required to take the results beyond that discussion.

E3 – What is the maturity of Green ICT for the measured organizations?
The average maturity for all organizations is at the level initial. Organizations are aware of the concepts and topics, but no implementations are truly done. Specific topics are rated higher, but many others are rated much lower taking the average score down. This level also feels appropriate when reviewing the public information.

The objective of the research was to develop a Green ICT maturity model with a specific focus on industrial manufacturing. The goal has succeeded, where the GITMM-MANU has been verified in a real life setting with input from industry experts. Although the GITMM-MANU will require several enhancements for further use, the overall feedback was positive and accurate for the industry.

6.3. Recommendations for practice

The GITMM-MANU developed for this project can be used in a practical setting. As a result of creating the GITMM-MANU, the researcher has uncovered several practical considerations:

- **Project organization**
  For the success of a maturity assessment it is important to ensure executive sponsorship

(buy-in), and ample access to specialists within the organization will determine the quality of the assessment outcome.

- **Scope and utility of the assessment**
  It is easy to misunderstand the intent and scope of any assessment project. Specifically, for a complex environment such as manufacturing, it is important to align the scope and intent with the specifics of the participating organization.
- **Develop awareness**
  When an organization starts the development of a sustainability practice, awareness should be a major element in this journey. Awareness and participation at all levels will increase the changes of real change within the organization.

6.4. Recommendations for further research

Several topics have emerged through this research that can be evaluated as recommendations for further research.

- **GITMM-MANU improvements**
  Based on the conclusions for the question E1, several recommendations have been made to improve the GITMM-MANU. Some recommendations are small, but others such as a fifth domain and auxiliary manufacturing topics are much bigger that can warrant their own research.
- **Impact**
  During the research all respondents questioned what the impact would be if certain components would be further optimized. Even if an organization wants to do the right thing, they struggle to determine where to start, which is where additional research into the impact of activities can help organizations make better decisions.
- **Manufacturing Logistics**
  The GITMM-MANU has a specific focus on the operational lifecycle for large complex assets. Related to this operational phase are supply chain and logistical processes for how a company receives and delivers their product. From the interviews we have learned that these have a large footprint, that can be researched.
- **Asset Development**
  While many decisions are made during the operational phase, equally so, an argument can be made regarding how Green ICT can influence sustainability during the engineering and construction phase of an asset. Many new technologies such as generative design, additive manufacturing, and digital twin can have a positive influence on how these assets are engineered, constructed, and commissioned.
- **Relationship with United Nations Sustainable Development Goals**
  As part of the introduction, the researcher explained how the United Nations have defined 17 SDG's (Sustainable Development Goals). Further research can be done to understand how companies can translate their activities in relationship with Green ICT and the SDG's.
- **Geographic differences**
  From the results of the interviews as well as the research described by KPMG (Blasco & King, 2017, p. 42), there seem to be regional differences. This is an excellent source for further research.

6.5. Reflection

Hindsight is a wonderful thing; it is how we capture this hindsight and subsequently learn from it is what makes it valuable. Different aspects will be discussed from the point of view of the researcher as well as the research process and product.

From a personal point of view, the research process has brought a new level of experience. Applying research techniques, even in a practical limited setting is challenging and fun at the same time. Although the research topic was initially met with a light level of scepticism in terms of interest, over time the topic has grown on the researcher, understanding more deeply how technology can help humanity and the impact the manufacturing industry has. Looking back at the product, the process, and the research quality, Table 15 provides insight into strong and weak elements.

Table 15: Product and process reflection

Reflection	Strong elements	Weaknesses
Product	+ Is validated in a real-life setting + Is based on industry ISO standard + Is based on earlier used well proven generic models + Is easy to use + Provides an accurate high-level picture	- Limited to the operational aspect of a large asset - No insight with respect to impact or priority for the components in the GITMM-MANU - Limited components for strategy and policy - No relationship towards SDG's
Process	+ Followed a proven design method for development of a maturity model + Based on extensive literature study + Results contrasted with factors of influence for Green ICT	- Interviews are limited to 4 organizations, with a single individual - Interviews were done across different types of manufacturing companies - Limited amount of time
Internal validity	+ Interviews are verified and corroborated with public information + Responding participants are all experts in their respective field + All interviews have been verified	- Only 4 individuals participated - None of the respondents really paid attention to the attributes, which makes it difficult to conclude if they are correct or not. - Only one respondent retrieved information from other specialists, the other respondents explained how they were more experienced in domain 4 and limited in domains 1,2 and 3.
External validity	+ All organizations in the heavy industry (manufacturing, operating large physical assets)	- Geographic differences - Not the same type of manufacturing organizations - Unknown if the results are truly representative for the sector
Reliability	+ Carefully and detailed approach to documentation	-
Ethical	+ All information is anonymized + Participants acted voluntary	-

Concluding

- **Internal validity:** The internal validity is limited for the domains 1, 2 and 3. Three of the respondents were specialized on domain 4 and were limited in their knowledge for the first three domains. The internal validity is also limited because we were only able to interview one respondent per organization, versus the planned two.

- **External validity:** The external validity is limited because the organizations were from different geographies (U.S. and NL). From the maturity results, a difference was shown between the U.S. and NL but this was only from a single measurement.

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Appendix 1 – Overview of provided literature

This appendix provides an overview of the supplied articles that are used for the basis of the research for Green ICT and maturity models. In the table, the articles that are listed in italics and preceded with an asterisk are used for forward snowballing to find additional articles on this subject.

Table 16: Appendix 1, Overview of provided literature

Topic	Citation	Title	Publication year	Citations (G-Scholar & OU)
Green IT	*(Gangadharan, 2012)*	**Harnessing Green IT - Principles and Practices*	*2012*	*1210*
Green IT	*(Cooper, Vanessa; Molla, Alemayehu, Pittayachawan, 2009)*	**IT and Eco-sustainability: Developing and Validating a Green IT Readiness Model*	*2009*	*193*
Green IT	(Molla et al., 2011)	**The Green IT readiness (G-readiness) of organizations: An exploratory analysis of a construct and instrument*	*2011*	*99*
Green IT	(Khor et al., 2015)	Bridging the Gap of Green IT_IS and Sustainable Consumption	2015	26
Green IT	(David Patón-Romero et al., 2017)	A governance and management framework for Green IT	2017	23
Green IT	(Lennerfors Taro et al., 2015)	ICT and environmental sustainability in a changing society	2015	17
Green IT	(Counotte-Potman et al., 2010)	Duurzaamheid van ict-intensieve organisaties	2010	1
Green IT	(Curley, M., Kenneally, J., & Carcary, 2016)	Green IT (GIT) – BOOK	2016	-
Green IT & Maturity	*(Donnellan et al., 2011)*	**A capability maturity framework for sustainable information and communication technology*	*2011*	*151*
Green IT & Maturity	*(Cooper, Vanessa; Molla, 2009)*	**GREEN IT READINESS: A FRAMEWORK AND PRELIMINARY PROOF OF CONCEPT*	*2009*	*88*
Green IT & Maturity	*(Sang-Hyun et al., 2012)*	**Assessing and Managing an Organization's Green IT Maturity*	*2012*	*39*
Green IT & Maturity	(Curry & Donnellan, 2012)	Understanding the Maturity of Sustainable ICT	2012	36
Green IT & Maturity	(Philipson, 2010)	A Green ICT Framework Understanding and Measuring Green ICT	2010	27
Green IT & Maturity	Hankel, Albert; Oud, Lisa; Saan, Maiko; Lago, Patricia	A Maturity Model for Green ICT: The case of the SURF Green ICT Maturity Model	2014	24
Green IT & Maturity	(Buchalcevova, 2016)	Green ICT Maturity Model for Czech SMEs	2016	16
Green IT & Maturity	(Hankel et al., 2017)	Green ICT Assessment for Organisations	2017	5
Green IT & Maturity	(Lautenschutz et al., 2018)	A Comparative Analysis of Green ICT Maturity Models	2018	2
Green IT & Maturity	(Foogooa et al., 2015)	Green ICT Maturity Models Towards a general approach	2015	2
Green IT & Maturity	(Hankel, 2015)	Handleiding voor het SURF Groene ICT Maturity Model	2015	-
Maturity	(Paulk et al., 1993)	** Capability Maturity Model, Version 1*	*1993*	*2974*
Maturity	*(Becker et al., 2009)*	**Developing Maturity Models for IT Management*	*2009*	*818*
Maturity	(Pöppelbuß & Röglinger, 2011)	*What makes a useful maturity model? A framework of general design principles for maturity models and its demonstration in business process management	2011	235
Maturity	(Becker, Jorg; Knackstedt, Ralf; Poppelbus, 2009)	Dokumentationsqualität von Reifegradmodellentwicklungen	2009	28

Appendix 2 – Search query definitions

L3 - Which criteria are relevant for Green ICT maturity models?

The following query model and parameters are used for searching for relevant articles.

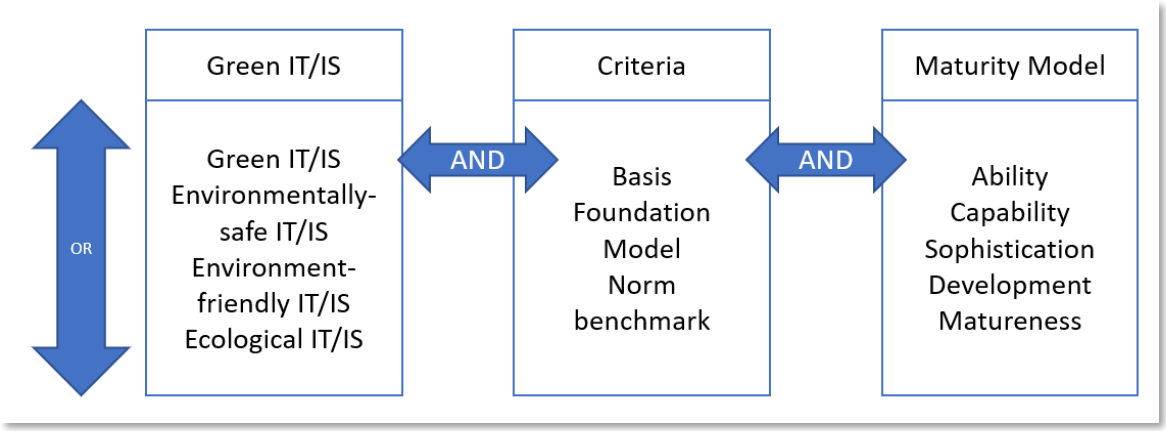


Figure 18: Appendix 2, Search Query Green ICT Maturity Models

In addition to the defined query, the search results will also be limited to the following options as available via the advanced search options for the universities library online:

Table 17: Appendix 2, Search criteria L3

Rule	Value	Reason
Publication Date	Last 5 years	The aim is to find newer research
Content Types	Journal Article	Journal articles typically of a higher quality versus articles that are not from a journal.
Disciplines	Business, Computer Science, Ecology, Environmental Sciences	This will limit the result set which helps with searching
Language	English	Other languages are omitted from this research
Limited to	Peer reviewed publications	Only verified reviewed articles are included
Excluded	Newspaper articles, Book Reviews, Dissertations	Non verified materials are specifically excluded
Expanded results	Results from outside the OU library will be included	This will also show results outside of the direct access, but the source might be limited.

L4. Which criteria are relevant for Green ICT maturity models for the process manufacturing industry?

The questions L4, L5 and L6 are closely related and the same parameters will be used for finding articles to address these questions.

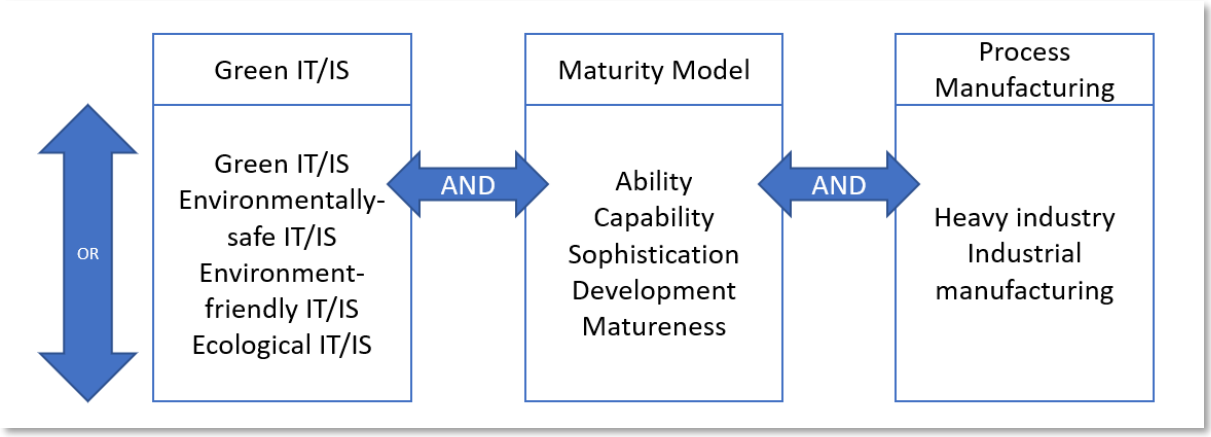


Figure 19: Appendix 2, Search Query Green, Maturity, and manufacturing

In addition to the defined query, the search results will also be limited to the following options as available via the advanced search options for the universities library online:

Table 18: Appendix 2, Search criteria L4

Publication Date	**Last 5 years**	**Reason**
Content Types	Journal Article	Journal articles typically of a higher quality versus non journal articles
Disciplines	Business, Computer Science, Ecology, Environmental Sciences, chemical, engineering	The disciplines are adjusted to also include specific manufacturing and engineering disciplines
Language	English	Other languages are omitted from this research
Limited to	Peer reviewed publications, Open Access Items only	Non verified materials are specifically excluded, in this case we specifically need articles and therefore we only selected open access items.
Excluded	Newspaper articles, Book Reviews, Dissertations	Specifically excluded are items that are not properly reviewed.

Appendix 3 – Forward snowballing, selected articles for review of L1 and L2

Table 19 provides an overview of the selected articles based on the forward snowballing method. The table has the following columns:

- Topic: A categorization assigned for the article
- Original Article: The set of selected articles that are used for the forward snowballing technique
- Selected citing article: An article that cited the original and was selected because of the high number of citations, publication year and keywords in the title
- Citations: The amount of citations in the selected article
- Publication year: The year the selected article was published
- Source: The initial start of the search either through the OU library or Google Scholar

Table 19: Appendix 3, Forward snowballing articles L1 and L2

Topic	Original article	Selected Citing article	Citations	Publication Year	Source
Green ICT	Harnessing Green IT - Principles and Practices (Gangadharan, 2012)	ICT for sustainability: An emerging research field (Hilty & Aebischer, 2015b)	158	2015	Google Scholar
Green ICT	IT and Eco-sustainability: Developing and Validating a Green IT Readiness Model, (Cooper, Vanessa; Molla, Alemayehu, Pittayachawan, 2009)	Impact of adoption of Green IT practices on organizational performance, (Ainin et al., 2016)	30	2016	Google Scholar
Green ICT	The Green IT readiness (G-readiness) of organizations: An exploratory analysis of a construct and instrument (Molla et al., 2011)	How IT executives create organizational benefits by translating environmental strategies into Green IS initiatives (Loeser et al., 2017)	35	2017	Google Scholar
Green ICT & Maturity	A capability maturity framework for sustainable information and communication technology (Donnellan et al., 2011)	A maturity model for Green ICT: The case of the SURF Green ICT maturity model [3] (Hankel et al., 2014)	24	2015	Google Scholar
Green ICT & Maturity	GREEN IT READINESS: A FRAMEWORK AND PRELIMINARY PROOF OF CONCEPT (Cooper, Vanessa; Molla, 2009)	Development of a Green ICT Model for Sustainable Enterprise Strategy (Anthony & Majid, 2016)	24	2016	Google Scholar
Green ICT & Maturity	Assessing and Managing an Organization's Green IT Maturity (Sang-Hyun et al., 2012)	A Systematic Literature Review of the Factors of Influence on the Environmental Impact of ICT	0	2018	OU – Web of Science
Maturity	Capability Maturity Model, Version 1 (Paulk et al., 1993)	If maturity is the answer, then exactly what was the question?	58	2014	Google Scholar

[3] The article from Hankel is also provided at the start of this research, but because of a lack of better articles based on the criteria we have selected this one.

Topic	Original article	Selected Citing article	Citations	Publication Year	Source
Maturity	Developing Maturity Models for IT Management (Becker et al., 2009)	The maturity of maturity model research: A systematic mapping study (Wendler, 2012)	162	2012[4]	Science Direct
Maturity	What makes a useful maturity model? A framework of general design principles for maturity models and its demonstration in business process management (Pöppelbuß & Röglinger, 2011)	BPM capability development – a matter of contingencies (Niehaves et al., 2014)	61	2014	Google Scholar

[4] Although the article was outside the criteria of the 5 years, because of the high citation count, the value based on the title and lack of better titles, this article was selected

Appendix 4 – Search iterations

Table 20 shows the various iterations in the search engines and the results.

- Q: Reference to the research question
- S. Pass: The search iteration
- Search Criteria: The criteria applied for the search
- Query: The query as entered in the search engine
- Hits OU: The amount of results the query returned for the library from the OU
- Hits Google Scholar: The amount of results the query returned for the Google Scholar Search Engine

Table 20: Appendix 4, Executed search iterations

Q	S. Pass	Search Criteria	Query	Hits OU	Hits Google Scholar
L3	1	Timeframe: last 5 years Content: Journal Article only Disciplines: Business, Computer Science, ecology, environmental sciences Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Environmentally safe IT" OR "Environmentally safe IS" OR "Ecological IT" OR "Ecological Is") AND ("Criteria" OR "BASIS" OR "Foundation" OR "Model" OR "Norm" OR "Benchmark") AND ("Maturity Model" OR "Ability" OR "Capability" OR "Sophistication" OR "Development" OR "Matureness")	273,933	17,600
L3	2	Timeframe: last 5 years Content: Journal Article only Disciplines: Business, Computer Science Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Environmentally safe IT" OR "Environmentally safe IS" OR "Ecological IT" OR "Ecological Is") AND ("Criteria" OR "BASIS" OR "Foundation" OR "Model" OR "Norm" OR "Benchmark") AND ("Maturity Mode" OR "Ability" OR "Capability" OR "Sophistication" OR "Development" OR "Matureness")	52,525	17,600
L3	3	Timeframe: last 5 years Content: Journal Article only Disciplines: Business Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Environmentally safe IT" OR "Environmentally safe IS" OR "Ecological IT" OR "Ecological Is") AND ("Criteria" OR "BASIS" OR "Foundation" OR "Model" OR "Norm" OR "Benchmark") AND ("Maturity Model" OR "Ability" OR "Capability" OR "Sophistication" OR "Development" OR "Matureness")	28,739	17,600

Q	S. Pass	Search Criteria	Query	Hits OU	Hits Google Scholar
L3	4	Timeframe: last 5 years Content: Any Type Disciplines: Any Type Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model")	738	534
L3	5	Timeframe: 2000 to 2013 Content: Any Type Disciplines: Any Type Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model")	483	416
L3	6	Timeframe: Last 5 years Content: Any Type Disciplines: Any Type Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS" OR "Sustainable IT" OR "Sustainable ICT") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model")	1546	678
L3	7	Timeframe: 2000 to 2013 Content: Any Type Disciplines: Any Type Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS" OR "Sustainable IT" OR "Sustainable ICT") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model")	1214	1280
Research Questions L4, L5 and L6					
L4, L5, L6	1	Timeframe: Last 5 years Content: Journal Article Disciplines: Business, Computer Science, Ecology, Environmental Sciences, chemistry, engineering Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Environmentally safe IT" OR "Environmentally safe IS" OR "Ecological IT" OR "Ecological Is") AND ("Maturity Model" OR "Ability" OR "Capability" OR "Sophistication" OR "Development" OR "Maturity") AND ("Process Manufacturing" OR "Heavy Industry" OR "Industrial" OR "Manufacturing")	214,620	18,300
L4, L5, L6	2	Timeframe: Last 5 years Content: Journal Article Disciplines: Any Discipline	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS" OR "Sustainable IT" OR "Sustainable ICT")	781	465

Q	S. Pass	Search Criteria	Query	Hits OU	Hits Google Scholar
		Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model") AND ("Process Manufacturing" OR "Industrial" OR "Manufacturing")		
L4, L5, L6	3	Timeframe: 2000 to 2013 Content: Journal Article Disciplines: Any Discipline Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green IS" OR "Green ICT" OR "Green IT/IS" OR "Sustainable IT" OR "Sustainable ICT") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model") AND ("Process Manufacturing" OR "Industrial" OR "Manufacturing")	369	281
L4, L5, L6	4	Timeframe: 2000 to 2013 Content: Journal Article Disciplines: Any Discipline Language: English Limit to: Peer Reviewed Journals Excluded: newspaper articles, book reviews, dissertations Expanded: Yes	("Green IT" OR "Green ICT" OR "Green IT/IS" OR "Sustainable IT" OR "Sustainable ICT") AND ("Maturity Model" OR "Capability Maturity Model" OR "Capability Model") AND ("Green Manufacturing")	22	24

Appendix 5 – Search results for L3 through L6

Table 21 describes the results of the search efforts. The table has the following columns:

- Title: The title of the article, conference proceeding or book that was found
- Year: The publication year for the found reference
- Categories: Based on a review of the title, abstract and scanning the article, the applicable categories for this research were applied
- Score: Based on the assigned categories, a score was applied based on the following formula:
  Each category represents a value, where all applicable categories have been added.
  Manufacturing and Sustainability: 1, Maturity Model, Green ICT and Process Manufacturing: 3
- IR: Include in Review, to indicate if the article will be used for a more detailed review
- Rejection reason: The reason for not including this article in further review
- Citation: The citation for this article, based on the APA style
- C. How often this article was cited by other authors, the number is a combination of the web science number presented by the OU library and the number presented by google scholar

Table 21: Appendix 5, Article Search results L3 to L6

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Environmental management maturity model for industrial companies	2017	Sustainability, Maturity Model, Manufacturing, Process Manufacturing,	8	y		Ormazabal, M., Sarriegi, J. M., & Viles, E. (2017). Environmental management maturity model for industrial companies. Management of Environmental Quality: An International Journal, 28(5), 632-650. doi:10.1108/MEQ-01-2016-0004	5
Investigating factors influencing decision-makers' intention to adopt Green IT in Malaysian manufacturing industry	2019	Sustainability, Green ICT, Manufacturing, Process Manufacturing,	8	y		Asadi, S., Nilashi, M., Safaei, M., Abdullah, R., Saeed, F., Yadegaridehkordi, E., & Samad, S. (2019). Investigating factors influencing decision-makers' intention to adopt Green IT in malaysian manufacturing industry. Resources, Conservation & Recycling, 148, 36-54. doi:10.1016/j.resconrec.2019.04.028	3
A capability maturity framework for sustainable information and communication technology	2011	Sustainability, Green ICT, Maturity Model,	7	y		Donnellan, B., Sheridan, C., & Curry, E. (2011). A capability maturity framework for sustainable information and communication technology. IT Professional, 13(1), 33-40. doi:10.1109/MITP.2011.2	152
The Green IT Readiness (G-Readiness) of Organizations: An Exploratory Analysis of a Construct and Instrument.	2011	Sustainability, Green ICT, Maturity Model,	7	y		Molla, A., Cooper, V., & Pittayachawan, S. (2011). The Green IT readiness (G-readiness) of organizations: An exploratory analysis of a construct and instrument. Communications of the Association for Information Systems, 29, 1. doi:10.17705/1CAIS.02904	99
Developing a sustainable it capability: Lessons from intel's journey	2012	Sustainability, Green ICT, Maturity Model,	7	y		Curry, E., Guyon, B., Sheridan, C., & Donnellan, B. (2012). developing a sustainable it capability: Lessons from intel's journey. Mis Quarterly Executive, 11(2), 61-74.	52
Assessing and Managing an Organization's Green IT Maturity Making.	2012	Sustainability, Green ICT, Maturity Model,	7	y		Sang-Hyun, P., Jaekyung, E., & Joosung, J. L. (2012). Assessing and Managing an Organization's Green IT Maturity Making. MIS Quarterly, 11(3), 127–140.	39

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Understanding the maturity of sustainable ICT	2012	Sustainability, Green ICT, Maturity Model,	7	y		Curry, E., & Donnellan, B. (2012). Understanding the maturity of sustainable ICT. (2012th ed., pp. 203-216). Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-642-27488-6_12	36
A maturity model for assessing the digital readiness of manufacturing companies	2017	Maturity Model, Manufacturing, Process Manufacturing,	7	y		De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2017, September). A maturity model for assessing the digital readiness of manufacturing companies. In IFIP International Conference on Advances in Production Management Systems (pp. 13-20). Springer, Cham.	36
An exploratory study on environmental sustainability and IT use	2008	Sustainability, Green ICT, Maturity Model,	7	y		Sayeed, L., & Gill, S. (2008). An exploratory study on environmental sustainability and IT use. AMCIS 2008 Proceedings, 55	35
A maturity model for Green ICT: The case of the SURF Green ICT maturity model	2014	Sustainability, Green ICT, Maturity Model,	7	Y		Hankel, A., Oud, L., Saan, M., & Lago, P. (2015). A maturity model for Green ICT: The case of the SURF Green ICT maturity model.	24
From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations	2011	Sustainability, Green ICT, Maturity Model,	7	y		Erek, K. (2011). From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations. In European, Mediterranean & Middle Eastern Conference on Information Systems (Vol. 2011, pp. 766-781).	18
Green ICT maturity model for Czech SMEs	2015	Sustainability, Green ICT, Maturity Model,	7	y		Buchalcevova, A. (2015). Green ICT maturity model for Czech SMEs. Journal of Systems Integration, 6(1), 24-36.	16
The readiness self-assessment model for Green IT implementation in organizations	2014	Sustainability, Green ICT, Maturity Model,	7	y		Muladi, N., & Surendro, K. (2014). The readiness self-assessment model for Green IT implementation in organizations. Paper presented at the 146-151. doi:10.1109/ICAICTA.2014.7005931	16
A comprehensive and practical Green ICT framework	2011	Sustainability, Green ICT, Maturity Model,	7	Y		Philipson, G. (2010). A comprehensive and practical Green ICT framework. In Handbook of Research on Green ICT: Technology, Business and Social Perspectives (pp. 131-145). IGI Global.	12
SustainaBits: A framework and rating system for sustainable IT	2012	Sustainability, Green ICT, Maturity Model,	7	y		deMonsabert, S., Odeh, K., & Meszaros, J. (2012). SustainaBits: A framework and rating system for sustainable IT. Paper presented at the 1-9. doi:10.1109/IGCC.2012.6322293	11
A Framework for Green Computing	2011	Sustainability, Green ICT, Maturity Model,	7	y		Philipson, G. (2011). A framework for Green computing. International Journal of Green Computing (IJGC), 2(1), 12-26. doi:10.4018/jgc.2011010102	8
Green IT framework for small and medium scale Indian IT services companies	2010	Sustainability, Green ICT, Maturity Model,	7	y		Mohapatra, S., & Jindal, A. (2010). Green IT framework for small and medium scale Indian IT services companies. International Journal of Green Economics, 4(3), 245-261.	8
Green ICT assessment for organisations	2017	Sustainability, Green ICT, Maturity Model,	7	y		Hankel, A., Heimeriks, G., Lago, P., Utrecht University, Department of Innovation Studies, Copernicus Institute, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands, & Vrije Universiteit Amsterdam, Department of Computer Science, De Boelelaan 1018a, 1081 HV Amsterdam, The Netherlands. (2017). Green ICT assessment for organisations. Journal of ICT Standardization, 4(2), 87-110. doi:10.13052/jicts2245-800X.421	5
A self Green ICT maturity assessment tool for SMEs	2014	Sustainability, Green ICT, Maturity Model,	7	y		Foogooa, R., & Dookhitram, K. (2014, May). A self Green ICT maturity assessment tool for SMEs. In 2014 IST-Africa Conference Proceedings (pp. 1-9). IEEE.	5
Assessing Green IT maturity and providing Green it recommendations	2013	Sustainability, Green ICT, Maturity Model,	7	y		Desai, M. A., Bhatia, V., Kolli, S., & Raman, A. (2013). U.S. Patent Application No. 13/316,208.	4

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Maturity for Sustainability in IT: Introducing the MITS	*2013*	*Sustainability, Green ICT, Maturity Model,*	*7*	*N*	*Green IT Maturity, TEXT NOT AVAILABLE*	*Smeitink, M., & Spruit, M. (2013). Maturity for sustainability in IT: Introducing the MITS. International Journal of Information Technologies and Systems Approach (IJITSA), 6(1), 39-56.*	*4*
Green IT Governance and Management based on ISO/IEC 15504	2018	Sustainability, Green ICT, Maturity Model,	7	y		Patón-Romero, J. D., Baldassarre, M. T., Rodríguez, M., & Piattini, M. (2018). Green IT governance and management based on ISO/IEC 15504. Computer Standards & Interfaces, 60, 26-36. doi:10.1016/j.csi.2018.04.005	3
How organisations can assess and improve their Green ICT activities in a standard and efficient way	2016	Sustainability, Green ICT, Maturity Model,	7	Y		Hankel, A., & Lago, P. (2016). How organisations can assess and improve their Green ICT activities in a standard and efficient way. Paper presented at the 1-6. doi:10.1109/ITU-WT.2016.7805710	3
A comparative analysis of Green ICT maturity models	2018	Sustainability, Green ICT, Maturity Model,	7	y		Lautenschutz, D. L., España, S., Hankel, A. C., Overbeek, S. J., & Lago, P. (2018). A comparative analysis of Green ICT maturity models	2
A SPICE-based maturity model for the governance and management of Green IT	2017	Sustainability, Green ICT, Maturity Model,	7	y		Patón-Romero, J. D., Rodríguez, M., & Piattini, M. (2017, October). A SPICE-based maturity model for the governance and management of Green IT. In International Conference on Software Process Improvement and Capability Determination (pp. 143-155). Springer, Cham.	2
Green ICT maturity models Towards a general approach	2015	Sustainability, Green ICT, Maturity Model,	7	y		Foogooa, R., Bokhoree, C., & Dookhitram, K. (2015, December). Green ICT maturity models Towards a general approach. In 2015 International Conference on Computing, Communication and Security (ICCCS) (pp. 1-6). IEEE.	2
Evaluating Sustainability and Greening Methods: A Conceptual Model for Information Technology Management	2013	Sustainability, Green ICT, Maturity Model,	7	y		Jarmoszko, A. T., D'Onofrio, M., Lee-Partridge, J. E., & Petkova, O. (2013). Evaluating Sustainability and Greening Methods: A Conceptual Model for Information Technology Management. International Journal of Applied Logistics (IJAL), 4(3), 1-13.	2
Green IT maturity models: a systematic mapping study	*2017*	*Sustainability, Green ICT, Maturity Model,*	*7*	*N*	*Green IT, Maturity Models, SPANISH LANGUAGE*	*Patón-Romero, J. D., & Piattini, M. (2017, June). Green IT maturity models: a systematic mapping study. In 2017 12th Iberian Conference on Information Systems and Technologies (CISTI) (pp. 1-6). IEEE.*	*2*
Defining an auditing protocol to measure the maturity level of sustainable ICT in Utrecht University	2016	Sustainability, Green ICT, Maturity Model,	7	y		Porras, J., & Khan, F.A framework and a web application for self-assessment of sustainable Green ICT practices in SMEs doi:10.20944/PREPRINTS201809.0002.V1	1
Assessing Green IT Maturity and Recommendation of Improvement for Government Agencies in Thailand	2015	Sustainability, Green ICT, Maturity Model,	7	y		Ateetanan, P., & Usanavasin, S. (2015). Assessing Green IT Maturity and Recommendation of Improvement for Government Agencies in Thailand. TNI Journal of Business Administration and Languages, 3(2), 7-12.	1
A Framework of Green It Capability Maturity for It Product Lifecycle in UTM	*2014*	*Sustainability, Green ICT, Maturity Model,*	*7*	*N*	*Thesis, full text not available*	*Sakirin, T. (2014). A Framework of Green It Capability Maturity for It Product Lifecycle in UTM (Doctoral dissertation, Universiti Teknologi Malaysia).*	*1*
IT Governance and Green IT Model for Large Mauritian Organisations	*2016*	*Sustainability, Green ICT, Maturity Model,*	*7*	*N*	*full text not available*	*Hardin-Ramanan, S., Chang, P. V., & Issa, D. T. (2016). IT governance and Green IT model for large mauritian organisations*	*1*
Application of ISO/IEC 33000 to Green IT: A Case Study	2019	Sustainability, Green ICT, Maturity Model,	7	y		Paton-Romero, J. D., Baldassarre, M. T., Rodreguez, M., Perez-Canencio, J. G., Ojeda-Solarte, M. L., Rey-Piedrahita, A., & Piattini, M. (2019). Application of ISO/IEC 33000 to Green IT: A case study. IEEE Access, 7, 116380-116389. doi:10.1109/ACCESS.2019.2936451	0
Environmental Sciences Based Maturity Model on Green IT 3.0	2018	Sustainability, Green ICT, Maturity Model,	7	y		Müller, G., & Counotte, A. (2018). Environmental Sciences Based Maturity Model on Green IT 3.0.	0

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY	2011	Sustainability, Green ICT, Maturity Model,	7	y		Viaro, T. A., Vaccaro, G. L. R., & Scherrer, T. (2011). CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY. Proceedings of XVII ICIEOM, Belo Horizonte, Brazil, 4-7 October 2011.	0
Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach	2011	Sustainability, Green ICT, Maturity Model,	7	y		Deodhar, S. J., & Saxena, K. B. C. (2011). Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach. FIIB Business Review, 1(1), 48-53.	0
ICT for Eco-Sustainability	2010	Sustainability, Green ICT, Maturity Model,	7	y		Molla, A., Corbitt, B., & Deng, H. (2010). ICT for eco-sustainability: an assessment of the capability of the Australian ICT sector.	0
A Maturity Model based on CMMI for Governance and Management of Green IT	*2019*	*Sustainability, Green ICT, Maturity Model,*	*7*	*N*	*full text not available*	*Patón-Romero, J. D., Baldassarre, M. T., Rodríguez, M., & Piattini, M. (2019). Maturity model based on CMMI for governance and management of Green IT. IET Software.*	*0*
Assessing the Maturity of Green IT Adoption Within the Philippine Manufacturing Industry	2017	Sustainability, Green ICT, Maturity Model,	7	y		Hernandez, A. A. (2017). Assessing the maturity of Green IT adoption within the philippine manufacturing industry. International Journal of Sociotechnology and Knowledge Development (IJSKD), 9(2), 37-55. doi:10.4018/IJSKD.2017040103	
Energy and utility management maturity model for sustainable manufacturing process	2013	Sustainability, Maturity Model, Manufacturing,	5	y		Ngai, E. W. T., Chau, D. C. K., Poon, J. K. L., & To, C. K. M. (2013). Energy and utility management maturity model for sustainable manufacturing process. International Journal of Production Economics, 146(2), 453-464. doi:10.1016/j.ijpe.2012.12.018	121
Manufacturing service and its maturity model	*2012*	*Sustainability, Green IT, Manufacturing,*	*5*	*N*	*Focused on Green IT strategies, full text not available*	*Zhan, D. C., Cheng, Z., Zhao, X. B., Nie, L. S., & Xu, X. F. (2012). Manufacturing service and its maturity model. Computer Integrated Manufacturing Systems, 18(7), 1584-1594.*	*10*
Sustainability assessment in manufacturing organizations: development of assessment models	2018	Sustainability, Maturity Model, Manufacturing,	5	y		Sangwan, K. S., Bhakar, V., & Digalwar, A. K. (2018). Sustainability assessment in manufacturing organizations: Development of assessment models. Benchmarking: An International Journal, 25(3), 994-1027. doi:10.1108/BIJ-08-2017-0227	8
An energy management maturity model for multi-site industrial organisations with a global	2017	Sustainability, Maturity Model, Manufacturing,	5	Y		Finnerty, N., Sterling, R., Coakley, D., & Keane, M. M. (2017). An energy management maturity model for multi-site industrial organisations with a global presence. Journal of Cleaner Production, 167, 1232-1250. doi:10.1016/j.jclepro.2017.07.192	7
232 A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries	2014	Sustainability, Manufacturing, Process Manufacturing,	5	y		Acharya, S., Vadher, J., & Acharya, G. D. (2014). 232 A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries.	5
Information Systems Innovation for Environmental Sustainability	*2010*	*Sustainability, Green IT,*	*4*	*N*	*provides a framework for introduction of Green IS, not relevant for answering the Research Question*	*Melville, N. P. (2010). Information systems innovation for environmental sustainability. MIS Quarterly, 34(1), 1-21. doi:10.2307/20721412*	*1311*
A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	2016	Maturity Model, Manufacturing,	4	Y		Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Procedia Cirp, 52, 161-166.	278
Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies	*2013*	*Maturity Model, Manufacturing,*	*4*	*N*	*Does not cover Green IT or Green IS and focused on discrete manufacturing*	*Pigosso, D. C. A., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. Journal of Cleaner Production, 59, 160-173. doi:10.1016/j.jclepro.2013.06.040*	*275*

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Sustainability in information systems: assortment of current practices in IS organizations	*2009*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Erek, K., Schmidt, N. H., Zarnekow, R., & Kolbe, L. M. (2009). Sustainability in information systems: assortment of current practices in IS organizations. AMCIS 2009 Proceedings, 123*	*80*
ISO 50001 standard-based energy management maturity model – proposal and validation	*2016*	*Sustainability, Maturity Model,*	*4*	*N*	*Not related to Green IT*	*Jovanović, B., & Filipović, J. (2016). ISO 50001 standard-based energy management maturity model – proposal and validation in industry. Journal of Cleaner Production, 112, 2744-2755. doi:10.1016/j.jclepro.2015.10.023*	*74*
What IS can do for environmental sustainability: a report from CAiSE'11 panel on Green and sustainable IS	*2012*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Pernici, B., Aiello, M., vom Brocke, J., Donnellan, B., Gelenbe, E., & Kretsis, M. (2012). What IS can do for environmental sustainability: A report from CAiSE'11 panel on Green and sustainable IS. Communications of the Association for Information Systems, 30 doi:10.17705/1CAIS.03018*	*60*
The status quo and the prospect of Green IT and Green IS: a systematic literature review	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Esfahani, M. D., Rahman, A. A., & Zakaria, N. H. (2015). The status quo and the prospect of Green IT and Green IS: a systematic literature review. Journal of Soft Computing and Decision Support Systems, 2(1), 18-34.*	*41*
Developing ecological sustainability: a Green IS response model	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Green IS, no maturity, wrong industry*	*Developing ecological sustainability: a Green IS response model*	*31*
Sustainability in business process management research–a literature review	*2012*	*Sustainability, Green IT,*	*4*	*N*	*Focused on BPM and sustainability, text not available*	*Stolze, C., Semmler, G., & Thomas, O. (2012). Sustainability in business process management research–a literature review.*	*26*
A review of Green IS research and directions for future studies	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Wang, X., Brooks, S., & Sarker, S. (2015). A review of Green IS research and directions for future studies. Communications of the Association for Information Systems, 37, 395. doi:10.17705/1CAIS.03721*	*25*
Development of a Green ICT Model for Sustainable Enterprise Strategy	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Green IS Strategy, no maturity*	*Anthony, B. J., & Majid, M. A. (2016). Development of a Green ICT Model for Sustainable Enterprise Strategy. Journal of Soft Computing and Decision Support Systems, 3(3), 1-12.*	*24*
A Framework for Adoption and Implementation of Green IT/IS Practice in IT Governance	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Not related to Maturity and or the manufacturing industry*	*Jnr, B. A., & Pa, N. C. (2015, December). A Framework for Adoption and Implementation of Green IT/IS Practice in IT Governance. In The Third International Conference on Green Computing, Technology and Innovation (ICGCTI2015) (p. 38).*	*22*
A case based reasoning architecture and component based model for Green IS implementation and diffusion in organisation	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Anthony, B., Jr, & Pa, N. C. (2016). A case based reasoning architecture and component based model for Green IS implementation and diffusion in organisation. International Journal of Digital Information and Wireless Communications, 6(2), 97.*	*14*
A Green information technology governance framework for eco-environmental risk mitigation	*2017*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Jr, B. A., Majid, M. A., & Romli, A. (2017). A Green information technology governance framework for eco-environmental risk mitigation. Progress in Industrial Ecology, an International Journal, 11(1), 30-48.*	*11*
Knowledge management framework using Green IT to implement sustainable entrepreneur ecosystem	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Green IT Knowledge framework, not maturity or related to manufacturing*	*Uddin, M., Hindu, R. C., Alsaqour, R., Shah, A., Abubakar, A., & Saba, T. (2015). Knowledge management framework using Green IT to implement sustainable entrepreneur ecosystem. Applied Mathematics & Information Sciences, 9(5), 2703.*	*11*
Sustainability in information systems: Requirements and emerging technologies	*2012*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Sustainability in information systems: Requirements and emerging technologies*	*10*
ICT as an enabler for sustainable development: Reflections on opportunities and barriers	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Bull, R. (2015). ICT as an enabler for sustainable development: Reflections on opportunities and barriers. Journal of Information, Communication and Ethics in Society, 13(1), 19–23. https://doi.org/10.1108/JICES-12-2014-0061*	*9*
Green agile maturity model for global software development vendors	*2014*	*Sustainability, Green IT,*	*4*	*N*	*Green IT for software development, wrong industry and no maturity*	*Rashid, N., & Khan, S. U. (2014). Green agile maturity model for global software development vendors. Science International, 26(5).*	*9*

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Green IT Adoption: Lessons from the Philippines Business Process Outsourcing Industry	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Green IT, Adoption in developing countries and BPO, wrong industry and not maturity*	*Hernandez, A. A., & Ona, S. E. (2016). Green IT adoption: lessons from the Philippines business process outsourcing industry. International Journal of Social Ecology and Sustainable Development (IJSESD), 7(1), 1-34.*	*9*
Green information systems integration in information technology based organizations: an academic literature review	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Anthony, B. J. (2016). Green information systems integration in information technology based organizations: an academic literature review. Journal of Soft Computing and Decision Support Systems, 3(6), 45-66.*	*8*
Approaches and initiatives to Green IT strategy in business	*2011*	*Sustainability, Green IT,*	*4*	*N*	*Focused on Green It strategies, full text not available*	*Goel, A., Tiwary, A., & Schmidt, H. (2011). Approaches and initiatives to Green IT strategy in business. In Handbook of Research on Green ICT: Technology, Business and Social Perspectives (pp. 169-183). IGI Global.*	*5*
Green IS Management Framework Verification: Explicating the Enabling Capabilities of Green IS.	*2014*	*Sustainability, Green IT,*	*4*	*N*	*Green IS management Framework and Not maturity*	*Howard, G. R., Lubbe, S., Huisman, M., & Klopper, R. (2014, September). Green IS Management Framework Verification: Explicating the Enabling Capabilities of Green IS. In EnviroInfo (pp. 389-396).*	*5*
Enterprise Information Systems Capability and GHG Pollution Emissions Reductions	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Impact of Green IT on GHG, not maturity and or manufacturing industry - TEXT NOT AVAILABLE*	*Rush, D., Melville, N., Ramirez, R., & Kobelsky, K. (2015). Enterprise Information Systems Capability and GHG Pollution Emissions Reductions.*	*3*
Application of ISO 14000 to Information Technology Governance and Management	*2019*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity, to broad on Green, not industry specific*	*Patón-Romero, J. D., Baldassarre, M. T., Rodríguez, M., & Piattini, M. (2019). Application of ISO 14000 to information technology governance and management. Computer Standards & Interfaces, 65, 180-202. doi:10.1016/j.csi.2019.03.007*	*2*
Evaluating factors affect Green IT readiness (part 1)	*2015*	*Sustainability, Green IT,*	*4*	*N*	*Green IT, readiness, no maturity or industry specific*	*Alsultanny, Y. A., & Alnassar, F. M. (2015). Evaluating factors affect Green IT readiness (part 1). International Journal of Green Computing (IJGC), 6(2), 30-42.*	*2*
Effective Green IT Strategy in a UK Higher Education Institute	*2016*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity, to broad on Green, not industry specific*	*AlHarbi, L. M., & Pattinson, C. (2016). Effective Green IT strategy in a UK higher education institute. Paper presented at the 251-256. doi:10.1109/DASC-PICom-DataCom-CyberSciTec.2016.62*	*1*
A Capability Maturity Model for Life Cycle Management at the Industry Sector Level	*2018*	*Sustainability, Maturity Model,*	*4*	*N*	*Maturity for the wrong industry, no relation with Green IT*	*Seidel-Sterzik, H., McLaren, S., & Garnevska, E. (2018). A capability maturity model for life cycle management at the industry sector level. Sustainability, 10(7), 2496. doi:10.3390/su10072496*	*1*
A Systematic Literature Review of the Factors of Influence on the Environmental Impact of	*2018*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Hankel, A., Heimeriks, G., & Lago, P. (2018). A systematic literature review of the factors of influence on the environmental impact of ICT. Technologies, 6(3), 85. doi:10.3390/technologies6030085*	*0*
Green IT/IS Adoption within Organizations: A Systematic Literature Review and Research Agenda	*2018*	*Sustainability, Green IT,*	*4*	*N*	*Does not Cover Maturity*	*Esfahani, M. D., Shahbazi, H., Nilashi, M., & Samad, S. (2018). Green IT/IS Adoption within Organizations: A Systematic Literature Review and Research Agenda. Journal of Soft Computing and Decision Support Systems, 5(5), 8-42.*	*0*
Research and Application of Capability Maturity Model for Chinese Intelligent Manufacturing	2019	Manufacturing, Process Manufacturing,	4	Y		Hua, J., & Gaoc, S. (2019). Research and Application of Capability Maturity Model for Chinese Intelligent Manufacturing. Procedia CIRP, 83, 794-799.	0
Management Instruments for Sustainable Information Systems Management	*2011*	*Sustainability, Green IT,*	*4*	*N*	*Full Text not available - book*	*Erek, K., Schmidt, N. H., Zarnekow, R., & Kolbe, L. M. (2011). Management Instruments for Sustainable Information Systems Management. In Green Technologies: Concepts, Methodologies, Tools and Applications (pp. 1448-1465). IGI Global*	*0*
The maturity of maturity model research: A systematic mapping study	*2012*	*Maturity Model,*	*3*	*N*	*To Generic on Maturity*		*443*

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Capturing maturity of ICT applications in construction processes	*2012*	*Maturity Model,*	*3*	*N*	*No relationship with Green IT, Construction is relared to Manufacturing*	*Eadie, R., Perera, S., & Heaney, G. (2012). Capturing maturity of ICT applications in construction processes. Journal of Financial Management of Property and Construction, 17(2), 176-194. doi:10.1108/13664381211246624*	*17*
Green IT practice disclosure: An examination of corporate sustainability reporting in IT sector	*2017*	*Green IT,*	*3*	*N*	*Wrong industry and not focused on maturity*	*Deng, Q., Ji, S., & Wang, Y. (2017). Green IT practice disclosure: An examination of corporate sustainability reporting in IT sector. Journal of Information, Communication and Ethics in Society, 15(2), 145-164. doi:10.1108/JICES-12-2016-0046*	*8*
Enterprise maturity models: a systematic literature review	*2019*	*Maturity Model,*	*3*	*N*	*To Generic on Maturity*	*Santos-Neto, J. B. S. D., & Costa, A. P. C. S. (2019). Enterprise maturity models: a systematic literature review. Enterprise Information Systems, 13(5), 719-769.*	*4*
Angewandtes Semantisches Metamodell von Rechenzentren für Green IT	*2013*	*Green IT,*	*3*	*N*	*Focused on Datacentres, TEXT NOT AVAILABLE*	*Memari A. (2013) Angewandtes Semantisches Metamodell von Rechenzentren für Green IT. In: Marx Gómez J., Lang C., Wohlgemuth V. (eds) IT-gestütztes Ressourcen- und Energiemanagement. Springer Vieweg, Berlin, Heidelberg*	*1*
Assessment of lean and Green strategies by simulation of manufacturing systems in discrete production environments	*2013*	*Sustainability, Manufacturing,*	*2*	*N*	*Discrete Manufacturing and generic lean and Green, no relationship with IT*	*Diaz-Elsayed, N., Jondral, A., Greinacher, S., Dornfeld, D., & Lanza, G. (2013). Assessment of lean and Green strategies by simulation of manufacturing systems in discrete production environments. CIRP Annals - Manufacturing Technology, 62(1), 475-478. doi:10.1016/j.cirp.2013.03.066*	*169*
Impacts of energy management practices on energy efficiency and carbon emissions reduction: A survey of malaysian manufacturing firms	*2017*	*Sustainability, Manufacturing,*	*2*	*N*	*Not Green IT, energy management, not maturity*	*Fernando, Y., & Hor, W. L. (2017). Impacts of energy management practices on energy efficiency and carbon emissions reduction: A survey of malaysian manufacturing firms. Resources, Conservation & Recycling, 126, 62-73. doi:10.1016/j.resconrec.2017.07.023*	*57*
How does ecological responsibility affect manufacturing firms' environmental and economic performance?	*2014*	*Sustainability, Manufacturing,*	*2*	*N*	*manufacturing- supply chaing management* *NOT Green IT*	*Koo, C., Chung, N., & Ryoo, S. Y. (2014). How does ecological responsibility affect manufacturing firms' environmental and economic performance? Total Quality Management & Business Excellence, 25(9-10), 1171-1189. doi:10.1080/14783363.2013.835615*	*51*
Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy	2019	Sustainability, Manufacturing,	2	Y		Cai, W., Lai, K., Liu, C., Wei, F., Ma, M., Jia, S., . . . Lv, L. (2019). Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy. Science of the Total Environment, 665, 23-32. doi:10.1016/j.scitotenv.2019.02.069	45
How Green is manufacturing? Status and prospects of national Green industrialisation. The case of Morocco	*2018*	*Sustainability, Manufacturing,*	*2*	*N*	*Not Green IT*	*Alba, J. M. D., & Todorov, V. (2018). How Green is manufacturing? status and prospects of national Green industrialisation. the case of morocco. International Journal of Innovation and Sustainable Development, 12(3), 308. doi:10.1504/IJISD.2018.091519*	*0*
Creating an enterprise-level "Green" strategy	*2008*	*Sustainability,*	*1*	*N*	*not focused on Maturity and or relation with manufacturing*	*Olson, E. G. (2008). Creating an enterprise-level "Green" strategy. Journal of Business Strategy, 29(2), 22-30. doi:10.1108/02756660810858125*	*198*
ENVIRONMENTAL CAPABILITIES AND CORPORATE STRATEGY: EXPLORING ACQUISITIONS AMONG US MANUFACTURING FIRMS	*2012*	*Manufacturing,*	*1*	*N*	*Not related to Green IT and or maturity*	*ERCHICCI, L., DOWELL, G., & KING, A. A. (2012). environmental capabilities and corporate strategy: Exploring acquisitions among us manufacturing firms. Strategic Management Journal, 33(9), 1053-1071. doi:10.1002/smj.1960*	*133*
Framing maturity based on sustainable operations management principles	*2017*	*Sustainability,*	*1*	*N*	*No Green IT, wrong industry, maturity sustainability*	*Machado, C. G., Pinheiro de Lima, E., Gouvea da Costa, Sergio Eduardo, Angelis, J. J., Mattioda, R. A., Industriell ekonomi och organisation (Inst.), . . . Industriell Management. (2017). Framing maturity based on sustainable operations management principles. International Journal of Production Economics, 190, 3-21. doi:10.1016/j.ijpe.2017.01.020*	*26*

Title	Year	Categories	Score	IR	Rejection Reason	Citation	C.
Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing: Moving to smart factories presents specific…	*2018*	*Manufacturing,*	*1*	*N*	*Does not cover Green IT or Green IS and focused on discrete manufacturing*	*Sjödin, D., Parida, V., Leksell, M., Petrovic, A., Institutionen för ekonomi, teknik och samhälle, Centre for Management of Innovation and Technology in Process Industry, Promote, . . . Luleå tekniska universitet. (2018). Smart factory implementation and process innovation: A preliminary maturity model for leveraging digitalization in manufacturing : Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. Research Technology Management, 61(5), 22.*	*16*
Energy sustainability for production design and operations	*2013*	*Sustainability,*	*1*	*N*	*Not Green IT, wrong industry, not maturity, full text not available*	*gai, E. W. T., Daniel Ng, C. T., & Huang, G. Q. (2013). Energy sustainability for production design and operations. International Journal of Production Economics, 146(2), 383-385. doi:10.1016/j.ijpe.2013.10.002*	*12*
Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: A methodology	*2017*	*Manufacturing,*	*1*	*N*	*No Green IT, Industrial organizations*	*Finnerty, N., Sterling, R., Coakley, D., Contreras, S., Coffey, R., & Keane, M. M. (2017). Development of a global energy management system for non-energy intensive multi-site industrial organisations: A methodology. Energy, 136, 16-31. doi:10.1016/j.energy.2016.10.049*	*9*
Sustainable IT Governance (SITG): Is COBIT 5 An Adequate Model	*2015*	*Sustainability,*	*1*	*N*	*COBIT 5 and support for sustainability, does not provide a maturity model*	*Merhout, J. W., & O'Toole, J. (2015). Sustainable IT Governance (SITG): Is COBIT 5 An Adequate Model. AIS Electronic Library: Newark, NJ, USA.*	*8*
A curriculum on sustainable information communication technology	*2015*	*Sustainability,*	*1*	*N*	*Learning course on Green IT, not maturity or industry specific, TEXT NOT AVAILABLE*	*Özkan, B., & Mishra, A. (2015). A curriculum on sustainable information communication technology. PROBLEMY EKOROZWOJU–PROBLEMS OF SUSTAINABLE DEVELOPMENT, 10(2), 95-101.*	*6*
Top tips for going Green: 15 simple steps towards making a big difference	*2008*	*Sustainability,*	*1*	*N*	*Green Practices, but not IT and industry specific*	*Top tips for going Green: 15 simple steps towards making a big difference. (2008). Strategic Direction, 24(6), 10-12. doi:10.1108/02580540810867998*	*0*

Appendix 6 – Design principles scoring

This appendix provides details of how the various articles are scored against the design principles. Each design principle represents a value of 1, where all design principles totalled for an article provide a total value. For descriptive models there is a maximum score of 15, for prescriptive models there is a maximum score of 18. The design principles are provided by Pöppelbuß, (Pöppelbuß & Röglinger, 2011).

The applicability of each score is based on reading each article in detail and determining if for that article the specific design principles are in place. Table 22 shows the scoring for each article against the design principles. Table 23 shows the article and the reference in APA style.

Table 22: Appendix 6, Design principles scoring per article

Design Principles	Article Title	Assessing and Managing an Organization's Green IT Maturity Making.	A maturity model for Green ICT: The case of the SURF Green ICT maturity model	A comprehensive and practical Green ICT framework	Green IT framework for small and medium scale Indian IT services companies	Green ICT maturity model for Czech SMEs	CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY	SustainaBits: A framework and rating system for sustainable IT	Assessing the Maturity of Green IT Adoption Within the Philippine Manufacturing Industry	From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations	Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach	Assessing Green it maturity and providing Green it recommendations	A capability maturity framework for sustainable information and communication technology
	Total Score (sum of all Design Principles)	**14**	**14**	**12**	**11**	**9**	**7**	**0**	**0**	**5**	**4**	**4**	**3**
DP 1.1	Application domain defined?	1	1	1	1	1	1			1	1	1	1
	Pre-requisites defined for the model?												
	Target Group defined for who apply the model and who results are reported to?		1										
	Differentiation with similar models clearly defined?	1	1		1	1							1
	Design of the maturity model properly documented?	1	1	1	1	1	1			1		1	
	Has the model been empirically validated?	1	1	1	1	1	1			1			
DP 1.2	Are central constructs defined for the model?	1	1	1	1	1	1				1	1	1
	Are the constructs multidimensional and descriptive?	1	1	1	1		1					1	
	Is each level described in a concise way?	1	1	1	1	1				1			

Design Principles	Article Title	Assessing and Managing an Organization's Green IT Maturity Making.	A maturity model for Green ICT: The case of the SURF Green ICT maturity model	A comprehensive and practical Green ICT framework	Green IT framework for small and medium scale Indian IT services companies	Green ICT maturity model for Czech SMEs	CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY	SustainaBits: A framework and rating system for sustainable IT	Assessing the Maturity of Green IT Adoption Within the Philippine Manufacturing Industry	From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations	Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach	Assessing Green it maturity and providing Green it recommendations	A capability maturity framework for sustainable information and communication technology
	Is there a logical relationship between the maturity levels?	1	1	1	1	1	1			1			
	Is there a solid relationship with a theoretical foundation?	1	1	1	1	1	1				1		
DP 1.3	Are the central constructs related to the applicable domain of the maturity model?	1	1	1	1	1					1		
DP 1.4	The documentation must be presented towards technological oriented audiences as well as management-oriented audiences.	1	1	1									
DP 2.1	The descriptive criteria for each maturity level, need to be precise, concise, and clear to discriminate between the different levels	1	1	1									
DP 2.2	Assessment methodology needs to be verifiable for a correct, accurate and repeatable outcome	1	1	1	1								
DP 3.1	For prescriptive models, each maturity level includes measures for how to improve to the next level	1											
DP 3.2	The prescriptive model needs to be provided with a decision calculus, to support the evaluation of different alternatives												
DP 3.3	A prescriptive model needs to guide users in making decisions for improvement as applicable for the target group												

The scored articles are listed in Table 23 including the citation for reference.

Table 23: Appendix 6, Scored Articles, and citations

Title	Citation
Assessing and Managing an Organization's Green IT Maturity Making.	Sang-Hyun, P., Jaekyung, E., & Joosung, J. L. (2012). Assessing and Managing an Organization's Green IT Maturity Making. MIS Quarterly, 11(3), 127–140.
A maturity model for Green ICT: The case of the SURF Green ICT maturity model	Hankel, A., Oud, L., Saan, M., & Lago, P. (2015). A maturity model for Green ICT: The case of the SURF Green ICT maturity model.
A comprehensive and practical Green ICT framework	Philipson, G. (2011). A comprehensive and practical Green ICT framework. In Handbook of Research on Green ICT: Technology, Business and Social Perspectives (pp. 131-145). IGI Global.
Green IT framework for small and medium scale Indian IT services companies	Mohapatra, S., & Jindal, A. (2010). Green IT framework for small and medium scale Indian IT services companies. International Journal of Green Economics, 4(3), 245-261.
Green ICT maturity model for Czech SMEs	Buchalcevova, A. (2015). Green ICT maturity model for Czech SMEs. Journal of Systems Integration, 6(1), 24-36.
CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY	Viaro, T. A., Vaccaro, G. L. R., & Scherrer, T. (2011). CONCEPTUAL MODEL TO ANALYSE GREEN MATURITY IN ORGANIZATIONS: PROPOSITION AND CASE STUDY. Proceedings of XVII ICIEOM, Belo Horizonte, Brazil, 4-7 October 2011.
SustainaBits: A framework and rating system for sustainable IT	deMonsabert, S., Odeh, K., & Meszaros, J. (2012). SustainaBits: A framework and rating system for sustainable IT. Paper presented at the 1-9. doi:10.1109/IGCC.2012.6322293
Assessing the Maturity of Green IT Adoption Within the Philippine Manufacturing Industry	Hernandez, A. A. (2017). Assessing the maturity of Green IT adoption within the philippine manufacturing industry. International Journal of Sociotechnology and Knowledge Development (IJSKD), 9(2), 37-55. doi:10.4018/IJSKD.2017040103
From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations	Erek, K. (2011). From Green IT to sustainable information systems management: Managing and measuring sustainability in IT organizations. In European, Mediterranean & Middle Eastern Conference on Information Systems (Vol. 2011, pp. 766-781).
Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach	Deodhar, S. J., & Saxena, K. B. C. (2011). Monitoring Information Technology for Environmental Sustainability: A Maturity Model Approach. FIIB Business Review, 1(1), 48-53.
Assessing Green it maturity and providing Green it recommendations	Desai, M. A., Bhatia, V., Kolli, S., & Raman, A. (2013). U.S. Patent Application No. 13/316,208.
A capability maturity framework for sustainable information and communication technology	Donnellan, B., Sheridan, C., & Curry, E. (2011). A capability maturity framework for sustainable information and communication technology. IT Professional, 13(1), 33-40. doi:10.1109/MITP.2011.2

Appendix 7 – GITMM-MANU combined with factors of influence

Table 24: Appendix 7, GITMM-MANU combined with factors of influence

Domain	Attribute	Component	Type of impact	Influence Factor
1 -Green ICT in the organization	10 - Procurement - Asset management	CMDB and service catalogs linked together	Direct impact of ICT / Direct Effects	use of ICT
		CMDB-based management of assets	Direct impact of ICT / Direct Effects	use of ICT
		Efficient IT asset replacement and lifecycle management	Direct impact of ICT / Direct Effects	Procurement
	11 - Procurement - Capital Cost	Consideration of Vendor carbon emissions when purchasing assets	Direct impact of ICT / Direct Effects	Procurement
		Existence and enforcement of rules requiring the use of environmental standards-compliant products	Societal impact on the organization	Compliance
		Green ICT Procurement	Direct impact of ICT / Direct Effects	Procurement
		Green ICT Supply Chain Management	Direct impact of ICT / Direct Effects	Procurement
		Use of energy efficiency-certified IT devices	Direct impact of ICT / Direct Effects	use of ICT
	12 - Procurement - Operating costs	Minimization of use of consumables	Direct impact of ICT / Direct Effects	Procurement
		Use of environmentally friendly office products	Organizational impact on ICT	Corporate policies
		Use of smart logistics	indirect impact of ICT / effects of use	Smart Logistics
	14 - Waste Management - Recycling and re-use	Re-use of consumables	Organizational impact on ICT	Corporate policies
		Rules requiring the re-use of assets	Direct impact of ICT / Direct Effects	use of ICT
	15 - Waste Management - Reduction of Resource use	Programs for encouraging staff participation in environmental campaigns	Organizational impact on ICT	Corporate policies
	16 - Waste Management - Waste Disposal	Control of toxic or harmful substances in items disposed of or sold off	Direct impact of ICT / Direct Effects	E-Waste
		E-Waste Policy	Direct impact of ICT / Direct Effects	E-Waste
		Incentives for waste reduction	Direct impact of ICT / Direct Effects	E-Waste
		Re-use of wastewater and recovery and re-use of waste heat	Organizational impact on ICT	Use of renewable energy
		Waste auditing and minimization of the environmental impact of production	Direct impact of ICT / Direct Effects	Production
	17 - Work Practices - Applications	Green ICT in Information Management and Architecture	Organizational impact on ICT	Strategy
		Application rationalization	Direct impact of ICT / Direct Effects	use of ICT
		Integrated communications tools	Direct impact of ICT / Direct Effects	use of ICT
	18 - Work Practices - Management	Green ICT Strategy	Organizational impact on ICT	Strategy
		Green leadership and administrative system	Organizational impact on ICT	Strategy
		ICT Governance	Organizational impact on ICT	Governance
		Environmental impact analysis	Societal impact on the organization	Transparency
		Internal cost sharing for IT services	Direct impact of ICT / Direct Effects	use of ICT
	19 - Work Practices - Operations	Community Collaboration	indirect impact of ICT / effects of use	Teleworking and Collaboration
2 - Green of ICT	02 - Data Center - Building Facilities	Automatic temperature and moisture control	indirect impact of ICT / effects of use	Smart Buildings
		Data center rationalization program	Direct impact of ICT / Direct Effects	use of ICT
		Efficient design of lighting systems	indirect impact of ICT / effects of use	Smart Energy
		Energy-efficient data centers	indirect impact of ICT / effects of use	Smart Energy
		housing	indirect impact of ICT / effects of use	Smart Buildings
		Real-time power consumption monitoring	indirect impact of ICT / effects of use	Smart Energy

Domain	Attribute	Component	Type of impact	Influence Factor
	03 - Data Center - Server Assets	Computing Infrastructure	Direct impact of ICT / Direct Effects	Use of ICT
		Intelligent refreshing	indirect impact of ICT / effects of use	Smart Energy
		Optimization of the use of server instances	Direct impact of ICT / Direct Effects	Use of ICT
		Server performance and power efficiency	indirect impact of ICT / effects of use	Smart Energy
		Use of a server virtualization solution	Direct impact of ICT / Direct Effects	Use of ICT
		Use of an orchestration tool	Direct impact of ICT / Direct Effects	Use of ICT
	04 - Data Center - Support Infrastructure	Backup software consolidated into a single platform	Direct impact of ICT / Direct Effects	Use of ICT
		Intelligent management of power allocation equipment	indirect impact of ICT / effects of use	Smart Energy
		Monitoring and management of storage equipment usage indicators	Direct impact of ICT / Direct Effects	Use of ICT
		Network convergence	Direct impact of ICT / Direct Effects	Use of ICT
		network infrastructure	Direct impact of ICT / Direct Effects	Use of ICT
		storage infrastructure	Direct impact of ICT / Direct Effects	Use of ICT
		Storage integration	Direct impact of ICT / Direct Effects	Use of ICT
	06 - Office Equipment - Office Equipment and Facilities	Automatic temperature control for office facilities	indirect impact of ICT / effects of use	Smart Buildings
		Fixed to wireless network migration	Direct impact of ICT / Direct Effects	Use of ICT
		Intelligent lighting system	indirect impact of ICT / effects of use	Smart Buildings
		Use of an energy-efficient lighting system	indirect impact of ICT / effects of use	Smart Energy
	07 - Office Equipment - PC's	Desktops replaced by laptops	Direct impact of ICT / Direct Effects	Use of ICT
		end user ICT equipment	Direct impact of ICT / Direct Effects	Use of ICT
		Power management system for IT devices	indirect impact of ICT / effects of use	Smart Energy
		Use of thin client solutions	Direct impact of ICT / Direct Effects	Use of ICT
	08 - Office Equipment - Printers	Use of multifunction, all-in-one printers	Direct impact of ICT / Direct Effects	Use of ICT
	15 - Waste Management - Reduction of Resource use	Use of smart redundancy	indirect impact of ICT / effects of use	Smart Energy
3 - Greening of Operations with ICT	06 - Office Equipment - Office Equipment and Facilities	Display screens powered off at night and during weekends	indirect impact of ICT / effects of use	Smart Energy
	07 - Office Equipment - PC's	Power shut off on unused IT devices	indirect impact of ICT / effects of use	Smart Energy
		Screen savers disabled	indirect impact of ICT / effects of use	Smart Energy
	08 - Office Equipment - Printers	Printers powered off at night and during weekends	indirect impact of ICT / effects of use	Smart Energy
		Use of integrated print management services	Direct impact of ICT / Direct Effects	Use of ICT
		Use of printing and toner saving solutions	Direct impact of ICT / Direct Effects	E-Waste
		Use of virtual fax services	Direct impact of ICT / Direct Effects	use of ICT
	15 - Waste Management - Reduction of Resource use	Electronic brochures for customers and distributors	indirect impact of ICT / effects of use	Paper Reduction
	17 - Work Practices - Applications	Digitization of work processes	indirect impact of ICT / effects of use	Paper Reduction
		Electronic approval enabled for work processes	indirect impact of ICT / effects of use	Paper Reduction
		Electronic customer invoices	indirect impact of ICT / effects of use	Paper Reduction
		Electronic payment processing and settlement with customers, vendors and partner businesses	indirect impact of ICT / effects of use	Paper Reduction
		Green Software Development	indirect impact of ICT / effects of use	Smart Energy

Domain	Attribute	Component	Type of impact	Influence Factor
		Internet-based sales channels	indirect impact of ICT / effects of use	E-Commerce
		paper reductions with ICT	indirect impact of ICT / effects of use	Paper Reduction
		Simplified and streamlined work processes	indirect impact of ICT / effects of use	Paper Reduction
	18 - Work Practices - Management	Software and ICT services	Direct impact of ICT / Direct Effects	Use of ICT
		Energy reductions with ICT	indirect impact of ICT / effects of use	Smart Energy
		Feedback and Decision Support	indirect impact of ICT / effects of use	Feedback and Reporting
		Carbon costs shared between sections and projects	Organizational impact on ICT	Governance
		Regular Green IT education provided to staff	Organizational impact on ICT	Strategy
	19 - Work Practices - Operations	Area reductions with ICT	indirect impact of ICT / effects of use	Teleworking and Collaboration
		Encouragement of and support for telecommuting	indirect impact of ICT / effects of use	Teleworking and Collaboration
		Support for telecommuting and mobile Office	indirect impact of ICT / effects of use	Teleworking and Collaboration
		Travel Reductions with ICT	indirect impact of ICT / effects of use	Teleworking and Collaboration
		Use of videoconferencing	indirect impact of ICT / effects of use	Teleworking and Collaboration
4 - Green ICT in Manufacturing	00 - Asset Information	Asset Information Strategy (IAM 22)	Direct impact of ICT / Direct Effects	use of ICT
		Asset Information Strategy Objectives (IAM 22)	Direct impact of ICT / Direct Effects	use of ICT
		Asset Information Strategy Review (IAM 22)	Direct impact of ICT / Direct Effects	use of ICT
		Asset Information Standards for a group of similar assets (IAM 23)	indirect impact of ICT / effects of use	Paper Reduction
		Asset Information Standards for an individual asset (IAM 23)	indirect impact of ICT / effects of use	Paper Reduction
		Asset Information Systems for a group of similar assets (IAM 24)	indirect impact of ICT / effects of use	Paper Reduction
		Asset Information Systems for an individual asset (IAM 24)	indirect impact of ICT / effects of use	Paper Reduction
		Data & Information Management (IAM 25)	indirect impact of ICT / effects of use	Paper Reduction
	01 - Asset Making Decision Making	Capital Investment Decision-Making (IAM 6)	Organizational impact on ICT	Strategy
		Operations & Maintenance Decision-Making (IAM 7)	Organizational impact on ICT	Corporate policies
	05 - Life Cycle Delivery	Configuration Management (IAM 14)	Direct impact of ICT / Direct Effects	Use of ICT
		Fault & Incident Response at the asset (IAM 20)	Direct impact of ICT / Direct Effects	Production
		Fault & Incident Response advanced analytics (IAM 20)	Direct impact of ICT / Direct Effects	Production
		Maintenance Delivery Training (IAM 15)	Direct impact of ICT / Direct Effects	Teleworking and Collaboration
		Resource Management ERP in the enterprise (IAM 18)	Direct impact of ICT / Direct Effects	Use of ICT
		Resource Management ERP system (IAM 18)	Direct impact of ICT / Direct Effects	Use of ICT
		Asset Operations digital enterprise (IAM 17)	indirect impact of ICT / effects of use	Paper Reduction
		Asset Operations digital operations (IAM 17)	indirect impact of ICT / effects of use	Paper Reduction
		Maintenance Delivery paper reduction (IAM 15)	indirect impact of ICT / effects of use	Paper Reduction
		Maintenance Delivery reduction field verification (IAM 15)	indirect impact of ICT / effects of use	Paper Reduction
		Reliability Engineering Advanced ICT Applications (IAM 16)	indirect impact of ICT / effects of use	Feedback and Reporting
		Reliability Engineering Equipment catalog (IAM 16)	indirect impact of ICT / effects of use	Feedback and Reporting
		Shutdown & Outage Management across assets (IAM 19)	indirect impact of ICT / effects of use	Paper Reduction
		Shutdown & Outage Management systems (IAM 19)	indirect impact of ICT / effects of use	Paper Reduction
		Systems Engineering (IAM 13)	indirect impact of ICT / effects of use	Smart Motors
		Technical Standards & Legislation tools standardization (IAM 11)	indirect impact of ICT / effects of use	Paper Reduction

Domain	Attribute	Component	Type of impact	Influence Factor
		Technical Standards & Legislation optimized processes (IAM 11)	indirect impact of ICT / effects of use	Paper Reduction
	09 - Organization & People	Procurement & Supply Chain Management across assets (IAM 26)	Direct impact of ICT / Direct Effects	Use of ICT
		Procurement & Supply Chain Management at the asset (IAM 26)	Direct impact of ICT / Direct Effects	Use of ICT
		Organizational Culture Rewards (IAM 29)	Societal impact on the organization	Culture
		Organizational Culture Support (IAM 29)	Societal impact on the organization	Culture
		Organizational Culture Training (IAM 29)	Societal impact on the organization	Culture
	13 - Risk & Review	Stakeholder Engagement (IAM 39)	Organizational impact on ICT	External Interaction
		Stakeholder Engagement Information (IAM 39)	Organizational impact on ICT	External Interaction
		Stakeholder Engagement Metrics (IAM 39)	Organizational impact on ICT	External Interaction
		Sustainable Development (IAM 33)	Societal impact on the organization	Reputation
		Sustainable Development (IAM 33)	Societal impact on the organization	Reputation
		Sustainable Development (IAM 33)	Societal impact on the organization	Reputation

Appendix 8 – Green ICT Framework and types of impact

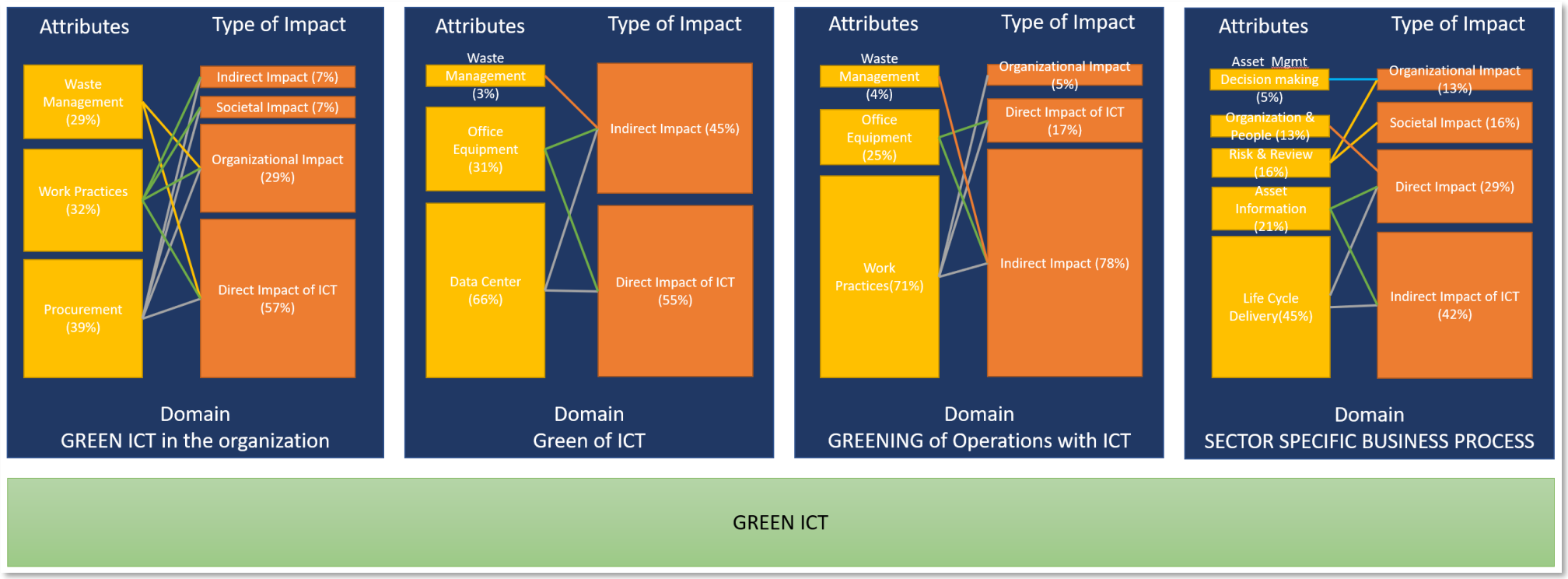


Figure 20: Appendix 8, Green ICT framework and types of impact

Appendix 9 – Review of criteria for manufacturing industry

This appendix contains two tables (Table 25 and Table 26) that describe the evaluation of the IAM subjects for inclusion and exclusion into the GITMM-MANU. The first table (Table 25) describes all the components that are included in the GITMM-MANU. The second table (Table 26) describes all the components that are **not** included in the model.

Table 25: Appendix 9, Criteria overview manufacturing industry included in the GITMM-MANU

Group	subject	Subject Description (IAM, 2015)	Potential Green ICT impact
Group 2 – Asset Management Decision Making	6.Capital Investment Decision-Making	The processes and decisions to evaluate and analyze scenarios for decisions related to capital investments of an organization. These processes and decisions may relate to new assets for the organization (e.g. Greenfield projects) and/or replacements of assets at end of life (CAPEX sustaining programs).	Capital investment decisions for an operational asset are related to large (technical) projects to extend or renew the facility. As part of these types of projects, the approach towards Green ICT can have an impact on how the company implements Green ICT.
	7.Opertions & Maintenance Decision - Making	The management activities and processes involved in determining the operations and maintenance requirements in support of the asset management objectives and goals.	The approach for operations and maintenance decision making have a direct impact towards Green ICT. It sets the direction for the company and puts focus on Green aspects or other aspects such as equipment reliability.
Group 3 – Life Cycle Delivery	11.Technical Standards & Legislation	The processes used by an organization to ensure its asset management activities are compliant with the relevant technical standards and legislation.	Operational assets need to adhere to many standards and regulations imposed internally or externally. The standardization of tools and processes have a positive influence on the environment by minimizing the use of energy, material usage and potential reduction in travel.
	13. Systems Engineering	An interdisciplinary, collaborative approach to derive, evolve and verify a life cycle balanced system solution that satisfies customer expectations and meets public acceptability. It describes policies and processes for the requirements analysis, design and evaluation of assets. Verification and validation execution are considered as part of asset creation and acquisition.	Systems Engineering describes how requirements are gathered, how design is executed and how assets are evaluated. ICT can have a major influence through utilization of real-time data, modern design and simulation tools and advanced analytics to ensure optimum operation.
	14. Configuration Management	A management process for establishing and maintaining consistency of a product's physical and functional attributes with its design and operational information	ICT can greatly support with configuration management of physical equipment utilized in the manufacturing facility.

Group	subject	Subject Description (IAM, 2015)	Potential Green ICT impact
		throughout its life. It is closely aligned with the principles and requirements of systems engineering.	This can support predictive and prescriptive maintenance to ensure longevity of the equipment, prevent breakdowns with potential environmental impacts and reduction of material and energy costs.
	15. Maintenance Delivery	The management of maintenance activities including both preventive and corrective maintenance management methodologies. It includes definition of maintenance specifications and schedules, maintenance execution procedures, procedures for missed maintenance and the capture and utilization of maintenance and inspection measurements and results.	Maintenance delivery can benefit from ICT using a tight integration between the physical asset and electronic records. Maintenance records and manuals can be produced and delivered in a digital method, preventing on-site duplication of paper. Modern collaboration tools can provide remote assistance and training preventing travel.
	16. Reliability Engineering	The processes for ensuring that an item shall operate to a defined standard for a defined period in a defined environment. Reliability engineering starts at the conceptual phase of design and continues through the life cycle. The goal is to identify potential reliability problems as early as possible in the life cycle and ensure that the reliability requirements will be met.	Asset simulation combined with Realtime data support reliability from initial design through decommissioning of equipment. Enhanced detection methods will detect potential failures early, preventing environmental challenges and reduction of energy.
	17. Asset Operations	The processes used by an organization to operate its assets to achieve the business objectives. It includes the processes that provide instructions to operators about how to operate the assets within the appropriate design, maintenance, and operational parameters.	ICT tools can support asset operations by digitizing training, operations, maintenance procedures and remote training.
	18. Resource management	Implementing the resourcing strategy to manage the use of funds, people, plant, tools and materials in delivering asset management activities. It includes integrating the resource utilization across the organization and across all asset management activities.	Resource management is greatly depending on ICT. Complex production schedules that require hundreds of employees to keep the asset running smooth in a 24x7 environment. The use of ICT supports an optimal balance of employees required for production as well as utilizing the amount of raw materials (feedstock), required for production. The more optimized these are, they have a great impact on energy consumption, raw material usage (prevent waste) and travel requirements for employees to be on-site.

Group	subject	Subject Description (IAM, 2015)	Potential Green ICT impact
	19. Shutdown & Outage Management	An organization's processes for identification, planning, scheduling, execution and control of work related to shutdowns or outages. It includes policies and processes for the implementation of the shutdown and outage strategy to ensure the effective management of shutdowns and outages.	Modern ICT tools support shutdown and outage management with planning and resource management tools to provide and optimum shutdown schedule. Preventing Shutdowns through preventive maintenance is linked to several activities listed earlier is where ICT can support.
	20. Fault & Incident Response	Responding to failures and incidents in a systematic manner, including incident detection and identification, fault analysis, use of standard responses, temporary and permanent repairs as well as the taking over and handing back of sites. It includes developing plans to respond to unplanned events and managing the resources required for the response to the events, and escalation criteria.	ICT can support with standardizing responses to failures and incidents. Providing timely and real-time information with modern communication and collaboration tools allows for faster and better responses, this in turn can prevent the environmental impact of the incident.
Group 4 – Asset Information	22. Asset Information Strategy	The strategic approach to the definition, collection, management, reporting and overall governance of asset information necessary to support the implementation of an organization's asset management strategy and objectives.	A strategic approach to Asset Information has Green ICT incorporated. Standardized approaches for technology and applications support a more efficient use of ICT resources.
	23. Asset Information Standards	The specification of a consistent structure and format for collecting and storing asset information and for reporting on the quality and accuracy of asset information.	Standardized asset information prevents information duplication and unnecessary use of ICT resources.
	24. Asset Information Systems	The asset information systems an organization has in place to support the asset management activities and decision-making processes in accordance with the asset information strategy.	Standardization of Asset information Systems can have enormous impact on sustainability, more efficient use of ICT resources, less training requirements, travel reduction and others are examples of potential benefits.
	25. Data & Information Management	The data and information held within an organization's asset information systems and the processes for the management and governance of that data and information.	Application and technology standardization provide better utilization of energy and storage resources. Standardizing the data stored for assets will allow for physical and virtual resource sharing.
Group 5 – Organization & People	26. Procurement & Supply Chain Management	The processes used by an organization to ensure that all outsourced asset management activities are aligned with the asset management objectives of the organization and to monitor the outcomes of these activities against these objectives.	Procurement and supply chain management has been extensively incorporated in the existing model and will not be included as a separate topic specific for the manufacturing industry.

Group	subject	Subject Description (IAM, 2015)	Potential Green ICT impact
	29. Organizational Culture	The culture of an organization in terms of its ability to deliver the organizational and asset management objectives.	Company culture is one of the factors of influence and has not been used in the model identified earlier. Culture describes the general attitude of employees towards environmental challenges and Green ICT activities.
Group 6 – Risk & Review	33. Sustainable Development	The interdisciplinary, collaborative processes used by an organization to ensure an enduring, balanced approach to economic activity, environmental responsibility and social progress to ensure all activities are sustainable in perpetuity.	Sustainable development activities describe to what extent the organization is actively pursuing sustainable development and has it incorporated in its processes for a balanced approach towards the economy, environmental responsibility and social progress.
	39. Stakeholder Engagement	The methods an organization uses to engage with stakeholders.	To what extent, methods and processes is the organization engaging with stakeholders on the level of Green ICT. Benefits include greater support for Green ICT initiatives.

The second table (Table 26) describes the components that are excluded from the GITMM-MANU.

Table 26: Appendix 9, Criteria overview manufacturing industry excluded from the GITMM-MANU

Group	Subject	Subject Description (IAM, 2015)	Reason for exclusion
Group 1 - Strategy & Planning	1. Asset Management Policy	This comprises the principles and mandated requirements derived from and consistent with the organizational plan, to provide a framework for the development and implementation of the strategic asset management plan (SAMP) and the setting of the asset management objectives.	This topic is more focused on the organizations approach towards asset management as a discipline. If the research would have been focused on the complete lifecycle, this would be an interesting for inclusion.
	2. Asset Management Strategy & Objectives	The strategic plan for the management of an organization's assets to achieve the organizational objectives. ISO 55000 refers to this asset management strategy as the Strategic Asset Management Plan (SAMP). The Strategy describes the long-term approach to management of the physical assets, specifies how organizational objectives are to be converted into asset management objectives, the approach for developing asset management plan(s), and the role of the AMS in supporting achievement of the asset management objectives.	The describes the overall strategy of the organization for the full lifecycle, which was considered out of scope of this research. The strategy and decision-making elements for operations and maintenance have been included (2.6 and 2.7)
	3. Demand Analysis	The processes an organization uses to both assess and influence the demand for, and level of service from, an organization's assets. It	Demand analysis describes the organizations capabilities, tools and methods to determine the

Group	Subject	Subject Description (IAM, 2015)	Reason for exclusion
		typically includes the analysis of future demand for the product or services being offered and the requirements this demand will place on the asset portfolio.	needs for a specific product across a portfolio of assets. This subject is out of scope for the purpose of this research.
	4. Strategic Planning	The processes an organization uses to undertake strategic asset management planning, to establish asset management objectives and develop the asset management strategy (SAMP). It includes how the organization is to address the outputs from demand analysis; the processes for determining long-term renewal, enhancement and maintenance work volumes; and the associated risks and costs to meet the asset management objectives. Asset management strategic planning is usually undertaken as part of the overall organizational strategic planning process.	The same rationale as for 1.2 is applied where there focus of this subject is too broad for the scope of this research.
	5. Asset Management Planning	The activities to develop the asset management plan(s) that specify the detailed activities, resources, responsibilities, timescales and risks for the achievement of the asset management objectives. Asset management planning follows on from the strategic planning process.	Based on the strategic plans and demand analysis, plans are put on place to plan for assets. This subject is outside of the operational phase and therefore out of scope.
Group 2 – Asset Management Decision Making	8. Lifecycle Value Realization	The activities undertaken by an organization to balance the costs and benefits of different renewal, maintenance, overhaul and disposal interventions. It includes the methods used to ensure the best total value is obtained, by consideration of the interaction between the life cycle activities, and determination of the optimal combination, including costs, risks, performance and sustainability effects. The total value usually needs to be considered at the level of asset system or asset portfolio.	This subject address more financial aspects of the overall asset lifecycle and is not focused enough on the operational phase of the asset and is therefore considered out of scope for this research.
	9. Resourcing Strategy	Determining and documenting the activities and processes to be undertaken by an organization in order to procure and use people, plant, tools and materials to deliver the asset management objectives and asset management plan(s). The resourcing strategy should consider the costs and risks of outsourcing the provision of resources, and how to best integrate the available resources across the organization in order to cost effectively deliver the asset management plan(s).	The research is focused on the engineering aspects of the operational lifecycle for assets and therefore this is considered out of scope for this research.
	10. Shutdowns & Outage Strategy	The activities taken by an organization to develop a strategy for shutdown and outages. It includes consideration of reducing downtime and outages, and the cost to carry out the activities in the asset management plan efficiently and safely during the planned outages.	This subject is covered by subject 19 for the operational phase of an asset and therefore considered out of scope.

Group	Subject	Subject Description (IAM, 2015)	Reason for exclusion
Group 3 - Life Cycle Delivery	12. Asset Creation & Acquisition	An organization's processes for the acquisition, creation, installation and commissioning of assets. It also includes elements of approval and releasing of funding, arrangements for hand-over to operations, the monitoring and capture of actual costs and benefits analysis.	Asset creation and or acquisition are considered out of scope with the focus of this research towards the operational phase of an asset.
	21. Asset Decommissioning and Disposal	The processes used by an organization to decommission and dispose of assets due to ageing or changes in performance and capacity requirements.	During the decommissioning and disposal phase of the asset lifecycle, sustainability and as an extension, Green ICT can be of huge importance. However, with a focus on the operational phase of the lifecycle this subject is considered out of scope. For future research this needs to be considered.
Group 5 - Organization & People	27. Asset Management Leadership	The leadership of an organization required to promote a whole life asset management approach to deliver the organizational and asset management objectives of the organization.	The asset management leadership subject is not specific enough to the operational phase of an asset.
	28. Organizational Structure	The structure of an organization in terms of its ability to deliver the organizational and asset management objectives.	This subject is focused on the organization as a whole and to broad for this research.
	30. Competence Management	The processes used by an organization to systematically develop and maintain an adequate supply of competent and motivated people to fulfil its asset management objectives including arrangements for managing competence in the boardroom and the workplace.	This subject is covered under subject 29 (4.32) in the model and therefore not included.
Group 6 - Risk & Review	31. Risk Assessment and Management	The policies and processes for identifying, quantifying and mitigating risk and exploiting opportunities.	Although new risks are emerging because of global warming (flooding, etc.), the subject is considered out of scope for this research with more of a focus on the operational aspects and engineering.
	32. Contingency Planning & Resilience Analysis	The processes and systems to ensure an organization is able to continue to either operate its assets to deliver the required level of service in the event of an adverse impact or maintain the safety and integrity of the assets (whether or not they operate).	This subject is broader than the scope of our research and considered out of scope.
	34. Management of Change	An organization's processes for the identification, assessment, implementation and communication of changes to people, processes and assets.	This considers generic change management outside and not specifically to the operational phase, which is specifically covered under 4.11 in the maturity model.
	35. Asset Performance &	The processes and measures used by an organization to assess the performance and health of its assets using performance indicators. The	Asset performance is related to the operational phase, however from a Green ICT maturity model

Group	Subject	Subject Description (IAM, 2015)	Reason for exclusion
	Health Monitoring	indicators can be leading or lagging and allow for the prediction of future asset performance and health as well as the assessment of current or historic performance.	for operations and engineering it was considered out of scope.
	36. Asset Management System Monitoring	The processes and measures used by an organization to assess the performance and health of its AMS. The primary aim is to evaluate the extent to which the AMS is fit for purpose and that the organization is delivering its asset management objectives.	This is more regarding the AMS system, versus the physical asset and therefore considered out of scope for this research.
	37. Management Review, Audit & Assurance	An organization's processes for reviewing and auditing the effectiveness of its asset management processes and AMS.	This is more regarding the AMS system, versus the physical asset and therefore considered out of scope for this research.
	38. Asset Costing & Valuation	An organization's processes for defining and capturing 'as built', maintenance and renewal unit costs and the methods used by an organization for the valuation and depreciation of its assets. This includes ensuring that the quality of financial information is appropriate for the financial reporting framework of the organization. The	This is more related to financial aspects of the physical asset and not directly related to operations and the combination with engineering.

Appendix 10 – Manufacturing Articles

Table 27: Appendix 10, Manufacturing Articles

Title	Citation	Review
Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy	Cai, W., Lai, K., Liu, C., Wei, F., Ma, M., Jia, S., . . . Lv, L. (2019). Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy. Science of the Total Environment, 665, 23-32. doi:10.1016/j.scitotenv.2019.02.069	Article has no relevance with Green ICT and or maturity models to establish criteria
Investigating factors influencing decision-makers' intention to adopt Green IT in Malaysian manufacturing industry	Asadi, S., Nilashi, M., Safaei, M., Abdullah, R., Saeed, F., Yadegaridehkordi, E., & Samad, S. (2019). Investigating factors influencing decision-makers' intention to adopt Green IT in malaysian manufacturing industry. Resources, Conservation & Recycling, 148, 36-54. doi:10.1016/j.resconrec.2019.04.028	Article describes decision factors and influences to select Green ICT, but does not describe a maturity model
Research and Application of Capability Maturity Model for Chinese Intelligent Manufacturing	Hua, J., & Gaoc, S. (2019). Research and Application of Capability Maturity Model for Chinese Intelligent Manufacturing. Procedia CIRP, 83, 794-799.	This maturity model is not related to Green ICT.
Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing: Moving to smart factories presents specific…	*Sjödin, D., Parida, V., Leksell, M., Petrovic, A., Institutionen för ekonomi, teknik och samhälle, Centre for Management of Innovation and Technology in Process Industry, Promote, . . . Luleå tekniska universitet. (2018). Smart factory implementation and process innovation: A preliminary maturity model for leveraging digitalization in manufacturing : Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. Research Technology Management, 61(5), 22.*	This is not a maturity model and focused on discrete manufacturing over process manufacturing
How Green is manufacturing? Status and prospects of national Green industrialisation. The case of Morocco	*Alba, J. M. D., & Todorov, V. (2018). How Green is manufacturing? status and prospects of national Green industrialisation. the case of morocco. International Journal of Innovation and Sustainable Development, 12(3), 308. doi:10.1504/IJISD.2018.091519*	*This is not a maturity model and provides a generic sustainable index for manufacturing in Marocco.*
Impacts of energy management practices on energy efficiency and carbon emissions reduction: A survey of malaysian manufacturing firms	*Fernando, Y., & Hor, W. L. (2017). Impacts of energy management practices on energy efficiency and carbon emissions reduction: A survey of malaysian manufacturing firms. Resources, Conservation & Recycling, 126, 62-73. doi:10.1016/j.resconrec.2017.07.023*	*This is also not a maturity model and has no relationship with Green ICT*
A maturity model for assessing the digital readiness of manufacturing companies	De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2017, September). A maturity model for assessing the digital readiness of manufacturing companies. In IFIP International Conference on Advances in Production Management Systems (pp. 13-20). Springer, Cham.	This is a maturity model that defines digital readiness and has no direct relationship with Green ICT
Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: A methodology	*Finnerty, N., Sterling, R., Coakley, D., Contreras, S., Coffey, R., & Keane, M. M. (2017). Development of a global energy management system for non-energy intensive multi-site industrial organisations: A methodology. Energy, 136, 16-31. doi:10.1016/j.energy.2016.10.049*	*Not a maturity model, not relationship with Green ICT*
A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Procedia Cirp, 52, 161-166.	A maturity model for industry 4.0 for discrete manufacturing and no relationship with process manufacturing and or Green ICT

Title	Citation	Review
How does ecological responsibility affect manufacturing firms' environmental and economic performance?	*Koo, C., Chung, N., & Ryoo, S. Y. (2014). How does ecological responsibility affect manufacturing firms' environmental and economic performance? Total Quality Management & Business Excellence, 25(9-10), 1171-1189. doi:10.1080/14783363.2013.835615*	*No maturity model and relationship with Green ICT*
232 A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries	Acharya, S., Vadher, J., & Acharya, G. D. (2014). 232 A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries.	Very specific to only foundry industries and no relationship with Green ICT
Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies	*Pigosso, D. C. A., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. Journal of Cleaner Production, 59, 160-173. doi:10.1016/j.jclepro.2013.06.040*	*No relationship with Green ICT*
Assessment of lean and Green strategies by simulation of manufacturing systems in discrete production environments	*Diaz-Elsayed, N., Jondral, A., Greinacher, S., Dornfeld, D., & Lanza, G. (2013). Assessment of lean and Green strategies by simulation of manufacturing systems in discrete production environments. CIRP Annals - Manufacturing Technology, 62(1), 475-478. doi:10.1016/j.cirp.2013.03.066*	*This is focused on discrete manufacturing*
ENVIRONMENTAL CAPABILITIES AND CORPORATE STRATEGY: EXPLORING ACQUISITIONS AMONG US MANUFACTURING FIRMS	*ERCHICCI, L., DOWELL, G., & KING, A. A. (2012). environmental capabilities and corporate strategy: Exploring acquisitions among us manufacturing firms. Strategic Management Journal, 33(9), 1053-1071. doi:10.1002/smj.1960*	*This is focused on acquisition strategies for manufacturing firms*
Manufacturing service and its maturity model	*Zhan, D. C., Cheng, Z., Zhao, X. B., Nie, L. S., & Xu, X. F. (2012). Manufacturing service and its maturity model. Computer Integrated Manufacturing Systems, 18(7), 1584-1594.*	*Copy of the article is not available*

Appendix 11 – Completed GITMM-MANU Framework

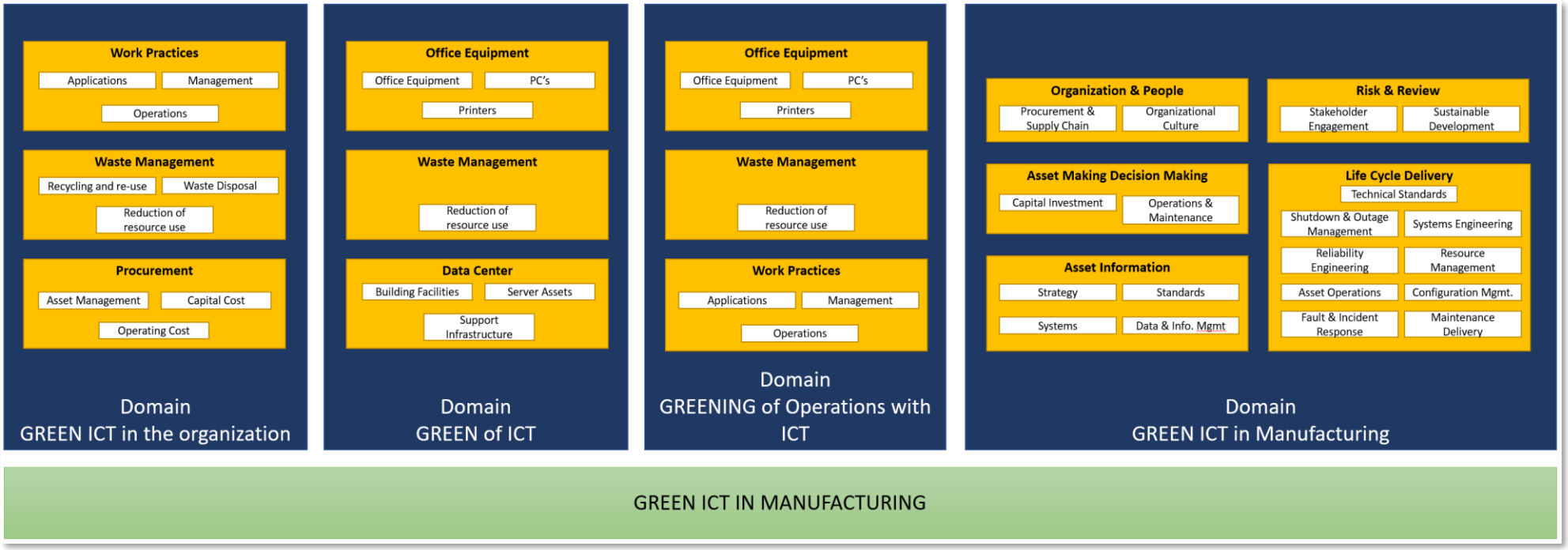


Figure 21: Appendix 11, Framework Green ICT in Manufacturing

Appendix 12 – Completed GITMM-MANU

The completed GITMM-MANU is provided in this appendix. Table 28 has several columns with the following explanation:

- **Domain**
  The domain represents a major component of the GITMM-MANU logically organizing attributes and components in organization areas. The number for the domains is based on the logical order as illustrated by Hankel.
- **Attribute**
  Each domain consists of several attributes. Each attribute is a grouping of processes or areas that logically fall within the domain they are a part of. The numbering of the attributes is cross domain and numbers are based on the alphabetical order of the attributes.
- **ID**
  The ID is defined by the researcher to provide a logical order to the questions.
- **Component**
  A component is the lowest level of the GITMM-MANU that describes a specific and concrete topic that can be scored.
- **Question / Explanation**
  The question / Explanation elaborates on the topic, therefore assisting the respondent of the GITMM-MANU to provide an accurate answer. Initial input for the questions is derived from the NIA report as applicable, new and added questions are added by the researcher (Lee et al., 2010).
- **Maturity level**
  The maturity level allows the respondent to rate their perceived maturity on a scale from 0 to 5. The following levels are utilized (Philipson, 2010).
  - 0 - No Intention - Never thought about it, no awareness
  - 1 – Initial - Some awareness. Considered, but not implemented
  - 2 – Replicable - Some ad hoc implementation, but no strategy
  - 3 – Defined - Formal programs have been defined, but implementation is immature
  - 4 – Managed - Methodical implementation of programs with adequate measurement and management
  - 5 – Optimised - All activities are monitored and managed for optimal performance. “Best practice”
- **Source**
  Components are marked differently to indicate the source of component.
  - Components derived from Hankel are **underlined** in blue.
  - Components derived from Sang-Huyn are regular script.
  - Components inspired by IAM and defined by researcher are ***italics*** in green.

Table 28: Appendix 12, Green ICT maturity model for manufacturing

Domain	Attribute	ID	Component	Question / Description	Maturity Score
1 -Green ICT in the organization	10 - Procurement - Asset management	1.09	Efficient IT asset replacement and lifecycle management	Is the lifecycle of IT assets efficiency managed under your company's asset management policy?	0 - No Intention
		1.10	CMDB-based management of assets	Are all asset purchase activities and power consumption tracked by a centrally managed configuration management database (CMDB) and included in the audit process?	0 - No Intention
		1.11	CMDB and service catalogs linked together	Is your company's configuration management database (CMDB) linked to its service catalog?	0 - No Intention
	11 - Procurement - Capital Cost	1.01	Green ICT Supply Chain Management	Does your ICT department consider its environmental impact for its activities as part of the supply chain and the effect this has on vendors, the ICT department and users?	0 - No Intention
		1.02	Green ICT Procurement	When selecting an asset does your company consider the total environmental impact on the company for owning the asset such as energy, consumables and disposing of the asset for its purchase decision?	0 - No Intention
		1.03	Consideration of Vendor carbon emissions when purchasing assets	When selecting an asset, does your company consider carbon emissions at the vendor's side, resulting from manufacturing, transportation and disposal processes, and has there been improvement in this area?	0 - No Intention
		1.04	Use of energy efficiency-certified IT devices	When selecting standard hardware solutions, is the energy efficiency of IT assets, including energy star certification, a key consideration?	0 - No Intention
		1.05	Existence and enforcement of rules requiring the use of environmental standards-compliant products	Does your company have rules requiring compliance with environmental regulations, such as EU Restriction of Hazardous Substance (RoHS) Directive and the Waste Electrical and Electronic Equipment (WEEE) Directive, and are the rules enforced?	0 - No Intention
	12 - Procurement - Operating costs	1.06	Use of environmentally friendly office products	Does your company have rules requiring the purchase of office supplies made with recycled/environment-friendly materials, and is encouraging compliance with these rules?	0 - No Intention
		1.07	Minimization of use of consumables	Does your company have a utility management process in place to minimize the use of consumables?	0 - No Intention
		1.08	Use of smart logistics	Does your company use a smart logistics system for product delivery? (ex. single packages, single pickup, etc.)	0 - No Intention
	14 - Waste Management - Recycling and re-use	1.12	Re-use of consumables	Are consumables like batteries and printer cartridges recycled or re-used in your company?	0 - No Intention
		1.13	Rules requiring the re-use of assets	Does your company have rules and processes in place for reusing computers and other internal assets by donating them or changing their intended use, and are these rules and processes effectively implemented?	0 - No Intention
	15 - Waste Management - Reduction of Resource use	1.14	Programs for encouraging staff participation in environmental campaigns	Does your company have set practices for its employees to participate in environmental movements, and has there been a continuous participation in environmental movements?	0 - No Intention
	16 - Waste Management - Waste Disposal	1.15	Control of toxic or harmful substances in items disposed of or sold off	Does your company conduct analysis on items that are sold or discarded, for instance, to define and classify hazardous substances?	0 - No Intention
		1.16	E-Waste Policy	To what extent has your company an E-Waste policy for ICT assets that is integrated in the daily operations and actively monitored and refined?	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
		1.17	Incentives for waste reduction	Does your company have incentive and information programs for reducing IT-related waste production, and are these programs conducted effectively?	0 - No Intention
		1.18	Re-use of wastewater and recovery and re-use of waste heat	Are wastewater and waste heat produced from offices and IT resources re-used in your company?	0 - No Intention
		1.19	Waste auditing and minimization of the environmental impact of production	Are all items audited before they are discarded, and has continuous improvement been made in terms of reduction of the environmental impact of your company's activities?	0 - No Intention
	17 - Work Practices - Applications	1.22	Green ICT in Information Management and Architecture	To what extent has the organization translated it's Green ICT strategy to policies, procedures and work instructions and incorporated Green ICT in it's architectural decision making for the organization?	0 - No Intention
		1.25	Application rationalization	Is your company conducting an application rationalization program to reduce the size of the application portfolio and achieve a company-wide standardized architecture?	0 - No Intention
		1.27	Integrated communications tools	Does your organization have a single, consolidated tool for communicating internal messages? (email, MSN, Skype, voicemail, fax, teams, etc.)?	0 - No Intention
	18 - Work Practices - Management	1.20	Green ICT Strategy	To what extent does the company have a Green ICT strategy that is comprehensive measurable and integrated at all levels of the organization?	0 - No Intention
		1.21	Green leadership and administrative system	Does your organization have a Green leadership program in place, along with well-defined rules and a management system? Also, is your organization carrying out a Green agenda?	0 - No Intention
		1.23	ICT Governance	Does your company have a governance model that controls ICT software and hardware and has Green ICT been incorporated in its governance model?	0 - No Intention
		1.24	Environmental impact analysis	Does your company conduct analysis on the environmental impact of its activities, concerning all business cases?	0 - No Intention
		1.26	Internal cost sharing for IT services	Does a charge-back mechanism for services provided by the IT unit exist in your company, and if so, is it appropriately managed?	0 - No Intention
	19 - Work Practices - Operations	1.28	Community Collaboration	Does your company use enterprise social networking tools for streamlined communication and reduced travel needs?	0 - No Intention
2 - Green of ICT	02 - Data Center - Building Facilities	2.01	housing	Does your company have a policy (guidelines that describes for new or existing datacenters an optimized use in terms of materials, energy efficiency and space in an effort to minimize environmental footprint.	0 - No Intention
		2.02	Automatic temperature and moisture control	Is the control of temperature and moisture in your data centers automated, and is the control system effective?	0 - No Intention
		2.03	Data center rationalization program	Is your company conducting a data center rationalization program to minimize the number of data centers?	0 - No Intention
		2.04	Efficient design of lighting systems	Is the lighting system in your data centers designed with energy efficiency in mind?	0 - No Intention
		2.05	Energy-efficient data centers	Was energy efficiency considered in the design of your data centers?	0 - No Intention
		2.06	Real-time power consumption monitoring	Is power usage monitored in real time in your company, and is monitored by each section or unit?	0 - No Intention
	03 - Data Center - Server Assets	2.07	Computing Infrastructure	Does your company have a policy in place that actively and continuously seeks to optimize the use of servers assets using both internal and cloud services infrastructure?	0 - No Intention
		2.08	Intelligent refreshing	Does your company practice intelligent refreshing in servers in all environments to improve their operation efficiency?	0 - No Intention
		2.09	Optimization of the use of server instances	Does your company collect data on the use of server instances across all your assets, manage related indicators and conduct optimization activities based on this information?	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
		2.10	Server performance and power efficiency	Are all servers in your company optimized based on their performance efficiency and highly efficient in terms of power supply?	0 - No Intention
		2.11	Use of a server virtualization solution	When developing information systems and introducing new servers in your operating environment, does your company consider server virtualization as a basic implementation method?	0 - No Intention
		2.12	Use of an orchestration tool	To proactively manage the floor space occupied by idle servers, does your company use orchestration tools in all environments?	0 - No Intention
	04 - Data Center - Support Infrastructure	2.13	Backup software consolidated into a single platform	Are backup software programs within your organization integrated into a single platform so that they may be used for company-wide backup and restoration?	0 - No Intention
		2.14	Intelligent management of power allocation equipment	Is your intelligent power allocation equipment installed in the LAC within the data centers and is linked with monitoring systems?	0 - No Intention
		2.15	Monitoring and management of storage equipment usage indicators	Does your company collect data on the use of storage equipment on all your assets and develop and manage related indicators?	0 - No Intention
		2.16	Network convergence	Have your networks been converged (voice/data, fixed/wireless) to reduce the number of switches needed in your data centers?	0 - No Intention
		2.17	network infrastructure	Does your company have a policy that actively and continuously seeks to optimize the use and traffic on networks in an effort to reduce the network equipment and power usage?	0 - No Intention
		2.18	storage infrastructure	Does your company have a policy that actively and continuously seeks to optimize storage needs through application of physical optimized infrastructure as well as managing data lifecycle for destruction of data where possible?	0 - No Intention
		2.19	Storage integration	Have your network storages in data centers been integrated to create a single-storage network?	0 - No Intention
	06 - Office Equipment - Office Equipment and Facilities	2.20	Automatic temperature control for office facilities	Is temperature in your offices controlled by a building control system, and is your company continuously improving the energy efficiency of the heating system?	0 - No Intention
		2.21	Fixed to wireless network migration	Do you have wireless network access in your organization to reduce the use of fixed-line networks?	0 - No Intention
		2.22	Intelligent lighting system	Is there an intelligent lighting system in all offices of your organization?	0 - No Intention
		2.23	Use of an energy-efficient lighting system	Is the lighting system in your organization energy-efficient?	0 - No Intention
	07 - Office Equipment - PC's	2.24	Desktops replaced by laptops	Have desktops been replaced by lower-power laptop computers in your company where possible?	0 - No Intention
		2.25	end user ICT equipment	Does your company have a policy in place that actively and continuously seeks to optimize end-user ICT equipment? (such as utilizing more efficient processing units, reduced consumables, reduce the need for printing, more efficient screens, etc.)?	0 - No Intention
		2.26	Power management system for IT devices	Are all IT equipment in your office controlled by a central power management system?	0 - No Intention
		2.27	Use of thin client solutions	Have your company's desktop units been replaced by thin client solutions where possible?	0 - No Intention
	08 - Office Equipment - Printers	2.28	Use of multifunction, all-in-one printers	Are multifunction devices functioning at the same time as a printer, fax machine, scanner and a photocopier used in your company, instead of separate devices?	0 - No Intention
	15 - Waste Management -	2.29	Use of smart redundancy	Does your company use smart redundancy techniques to reduce the number of physical apparatuses?	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
	Reduction of Resource use				
3 - Greening of Operations with ICT	06 - Office Equipment - Office Equipment and Facilities	3.02	Display screens powered off at night and during weekends	Is the power supply to printers in your organization shut off during weekends and night hours?	0 - No Intention
	07 - Office Equipment - PC's	3.03	Power shut off on unused IT devices	Are there rules in your company, requiring employees to shut off power to all unused PCs and IT devices, and a management system to monitor compliance?	0 - No Intention
		3.04	Screen savers disabled	Have screensavers been disabled in all display devices so that they go into power saving mode?	0 - No Intention
	08 - Office Equipment - Printers	3.05	Printers powered off at night and during weekends	Are all printers in your company configured so that power is automatically shut off during night hours and weekends?	0 - No Intention
		3.06	Use of integrated print management services	Do you have an integrated print management service in your organization to reduce unnecessary printed materials?	0 - No Intention
		3.07	Use of printing and toner saving solutions	Are all printers in your company installed with a toner saving solution?	0 - No Intention
		3.08	Use of virtual fax services	Is there support for a virtual fax service for all users in your company, and is its use widespread?	0 - No Intention
	15 - Waste Management - Reduction of Resource use	3.09	Electronic brochures for customers and distributors	Does your company encourage electronic distribution of product or company brochures to customers and vendors?	0 - No Intention
	17 - Work Practices - Applications	3.10	Digitization of work processes	Does your company have a policy that actively and continuously seeks to improve business processes in terms of resources required to perform these business processes?	0 - No Intention
		3.11	Electronic approval enabled for work processes	Can all employees in your company conduct their basic tasks through an electronic approval system or a web interface?	0 - No Intention
		3.12	Electronic customer invoices	Does your company use an e-billing system to issue paperless customer invoices (or payment receipts)?	0 - No Intention
		3.13	Electronic payment processing and settlement with customers, vendors and partner businesses	Does your company have and use an electronic payment/settlement system to settle transactions with customers or vendors?	0 - No Intention
		3.14	Green Software Development	Does your company have policies (guidelines or work instructions) that incorporate Green into the software development lifecycle to optimize the energy required? These can be techniques such as multi-threading, async IO, use of processor states, efficient algorithms, etc.	0 - No Intention
		3.15	Internet-based sales channels	Does your company have an internet-based sales channel?	0 - No Intention
		3.16	paper reductions with ICT	To what extent is your company actively and continuously improving paper-based processes to reduce the amount of paper used by the organization?	0 - No Intention
		3.17	Simplified and streamlined work processes	Are organizational processes in your company being thoroughly reviewed and continuously improved in order to reduce the number of tasks performed?	0 - No Intention
	18 - Work Practices - Management	3.18	Carbon costs shared between sections and projects	Does a model for charging back carbon costs to units and projects exist and are improvement activities carried out based on the charge-back model, in your company?	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
		3.19	Energy reductions with ICT	To what extent is the ICT department actively and continuously involved to seek new methods to reduce the overall companies resources footprint, such as intelligent heating (cooling) systems, intelligent lighting systems, smart monitoring solutions for the companies power grid and others where ICT can contribute?	0 - No Intention
		3.20	Feedback and Decision Support	Does your company have a program, where ICT is used to provide information regarding ICT resource usage (Energy, Consumables, Waste) back to the organization to better support decision making?	0 - No Intention
		3.22	Regular Green IT education provided to staff	Is Green IT education provided to employees in your company, on a regular basis?	0 - No Intention
		3.23	Software and ICT services	When ICT services (software, hardware, services) are procured or in-house developed, to what extent does your company have policies in place that seek to improve the energy consumption or lower the consumables utilized?	0 - No Intention
	19 - Work Practices - Operations	3.01	Area reductions with ICT	Does your company promote workspace reductions through the use of shared workspaces and optimized use of meeting rooms?	0 - No Intention
		3.24	Encouragement of and support for telecommuting	Does your company provide support tools and office space for telecommuting, and encourage telecommuting by employees?	0 - No Intention
		3.26	Support for telecommuting and mobile Office	Is your IT department capable of supporting telework force and mobile workforces through remote support services? (ex. IT support via remote control)	0 - No Intention
		3.27	Travel Reductions with ICT	Does your company provide tools and methods that support virtual teams to work collaboratively on tasks in a real time fashion that will reduce the need for physical presence and travel?	0 - No Intention
		3.28	Use of videoconferencing	Is a video conference system in place and in use, in your company, to minimize travel needs?	0 - No Intention
4 - Green ICT in Manufacturing	00 - Asset Information	*4.01*	*Asset Information Strategy (IAM 22)*	As part of the Asset Information strategy, to what extent has the organization incorporated Green practices in its strategy that will lower resource needs and prevent (e-) waste?	0 - No Intention
		4.02	*Asset Information Strategy Objectives (IAM 22)*	To what extent does the asset information strategy enable specific Green ICT objectives and plan(s) to be produced, optimized and prioritized?	0 - No Intention
		4.03	*Asset Information Strategy Review (IAM 22)*	To what extent is the asset information strategy, and it's approach to Green ICT, reviewed periodically to ensure it remains effective to the goals the organization has set?	0 - No Intention
		4.04	*Asset Information Standards for a group of similar assets (IAM 23)*	Within the context of similar production facilities (e.g. all oil refineries, or all blending facilities), to what extent are asset information standards defined and used? Utilizing the same information standards across a range of assets lowers the overall complexity of the information management systems.	0 - No Intention
		4.05	*Asset Information Standards for an individual asset (IAM 23)*	Within the context of an individual asset (single production location), to what extent is information managed in a consistent and standardized method? (e.g. all production equipment information has a single source of truth and this is not replicated into disconnected data sources). Efficient and consistent information standards, support Green ICT by lowering the need for storage and data management, but also a more efficient workforce.	0 - No Intention
		4.06	*Asset Information Systems for a group of similar assets (IAM 24)*	Within the context of similar production facilities (e.g. all oil refineries, or all blending facilities), to what extent are asset information systems standardized across these facilities in an effort to lower infrastructure requirements and centralize information management?	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
				(e.g. the maintenance management system is standardized on SAP, versus a unique system for each production facility)	
		4.07	*Asset Information Systems for an individual asset (IAM 24)*	Within the context of an individual asset (single production location), to what extent is there a consistent effort to modernize systems to streamline processes and reduce paper usage (e.g. approval of design documents for an MOC are converted to an electronic workflow process)?	0 - No Intention
		4.08	*Data & Information Management (IAM 25)*	To what extent does the company have a standardized governance model for data & information that lowers the complexity and training requirements across multiple assets? (e.g. are HSE audits conducted in the same manner, or is there a standard records management plan for destruction of facility records)	0 - No Intention
	01 - Asset Making Decision Making	*4.09*	*Capital Investment Decision-Making (IAM 6)*	To what extent has the company a strategy in place that incorporates Green ICT (i.e. smart manufacturing) in the decision making process?	0 - No Intention
		4.10	*Operations & Maintenance Decision-Making (IAM 7)*	To what extent has the company policies in place that drive (support) Green ICT initiatives as part of the day to day O&M decision making process?	0 - No Intention
	05 - Life Cycle Delivery	*4.11*	*Configuration Management (IAM 14)*	To what extent has the company a strategy towards establishing a "digital" twin of its assets? A digital twin provides a close to real-time 100% accurate digital representation of a physical asset that can be used for management of the functional and physical attributes and supports advanced analytics for predictive maintenance, reduce environmental risks and optimize operations.	0 - No Intention
		4.12	*Fault & Incident Response at the asset (IAM 20)*	To what extent does the company have a system in place to manage failures and incidents for asset?	0 - No Intention
		4.13	*Fault & Incident Response advanced analytics (IAM 20)*	To what extent are faults and incidents reported across assets through an automated system and is the data analysis to optimize safety and prevention of incidents?	0 - No Intention
		4.14	*Maintenance Delivery Training (IAM 15)*	To what extent has the company a strategy in place towards using virtual reality (AR/VR) for lowering personnel training cost or remote support of maintenance activities? The immediate effects of this are reduced travel requirements.	0 - No Intention
		4.15	*Resource Management ERP in the enterprise (IAM 18)*	To what extent has the company standardized the use of ERP technologies across multiple assets?	0 - No Intention
		4.16	*Resource Management ERP system (IAM 18)*	To what extent is the company utilizing an integrated ERP solution to manage funds, tools, people, materials, feedstock for an asset?	0 - No Intention
		4.17	*Asset Operations digital enterprise (IAM 17)*	To what extent has the company standardized the use of DCS / SCADA technologies across its assets? Standardization of DCS / SCADA technologies consolidates the ICT resources required.	0 - No Intention
		4.18	*Asset Operations digital operations (IAM 17)*	To what extent has the company digitized the operations room and removed the need for paper instructions and training information for operating the asset?	0 - No Intention
		4.19	*Maintenance Delivery paper reduction (IAM 15)*	To what extent has the company it's engineering records easily electronically available for maintenance purposes that completely negate the need for paper copies in the field? (i.e. onsite location)	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
		4.20	*Maintenance Delivery reduction field verification (IAM 15)*	To what extent has the company it's engineering records up to date and electronically available for maintenance purposes in a way that greatly reduce the need for field checks. (i.e. field checks are an activity where the company performs an audit of the physical situation compared to the engineering records to assess the actual situation before potential asset changes are evaluated).	0 - No Intention
		4.21	*Reliability Engineering Advanced ICT Applications (IAM 16)*	To what extent does the company utilize advanced ICT technologies (fluid dynamics simulation, mechanical integrity simulation, MTBF analytics, Real-Time data analytics, etc.) to improve the reliability of the equipment at the asset level?	0 - No Intention
		4.22	*Reliability Engineering Equipment catalog (IAM 16)*	To what extent does the company have a global equipment register that shares reliability and maintenance information for improved failure detection and improved maintenance?	0 - No Intention
		4.23	*Shutdown & Outage Management across assets (IAM 19)*	To what extent are systems, procedures and strategy replicated across assets, to manage shutdowns and outages?	0 - No Intention
		4.24	*Shutdown & Outage Management systems (IAM 19)*	To what extent is the company utilizing advanced planning, execution systems (e.g. primavera, procore) to manage shutdowns, outage management and related engineering and construction activities of the asset?	0 - No Intention
		4.25	*Systems Engineering (IAM 13)*	To what extent is sustainability (Green ICT) incorporated in the policies and processes for asset analysis, design and evaluation? (e.g. When purchasing new equipment, preferential factors are included with the selection process for equipment that is "smart" with advanced analytical data capabilities.)	0 - No Intention
		4.26	*Technical Standards & Legislation tools standardization (IAM 11)*	To what extent are tools and processes to manage technical asset standards & legislation (e.g. ASME, TCEQ, EPA, etc.) standardized across similar assets where possible?	0 - No Intention
		4.27	*Technical Standards & Legislation optimized processes (IAM 11)*	To what extent are the processes for managing standards and regulatory compliance designed around reduction of required resources? (e.g. paper reduction, electronic approvals, electronic submission to regulatory bodies, etc.)	0 - No Intention
	09 - Organization & People	*4.28*	*Procurement & Supply Chain Management across assets (IAM 26)*	to what extent are procurement systems standardized and consolidated across different assets?	0 - No Intention
		4.29	*Procurement & Supply Chain Management at the asset (IAM 26)*	To what extent has the company integrated it's supply chain with vendors and customers to perform asset operations. (e.g. feedstock supply, batch processing and information, customer supply, etc.)	0 - No Intention
		4.30	*Organizational Culture Rewards (IAM 29)*	To what extent are individuals recognized and rewarded for promoting sustainability (Green ICT) ideas and concepts for improving the organization?	0 - No Intention
		4.31	*Organizational Culture Support (IAM 29)*	To what extent has the organization a culture that promotes and fosters sustainability in the organization?	0 - No Intention
		4.32	*Organizational Culture Training (IAM 29)*	To what extent has the organization a training / awareness program that promotes sustainability for the company?	0 - No Intention
	13 - Risk & Review	*4.33*	*Stakeholder Engagement (IAM 39)*	To what extent does the organization engage with stakeholders to determine a Green (ICT) strategy for the company?	0 - No Intention
		4.34	*Stakeholder Engagement Information (IAM 39)*	Does the organization have a program for informing stakeholders on sustainability (Green ICT) matters?	0 - No Intention
		4.35	*Stakeholder Engagement Metrics (IAM 39)*	Does the organization report on specific sustainability (Green ICT) metrics? (e.g. the amount of Green (ICT) projects, the energy reduction as a percentage of the total energy consumption, etc.)	0 - No Intention

Domain	Attribute	ID	Component	Question / Description	Maturity Score
		4.36	*Sustainable Development (IAM 33)*	To what extent does the organization utilize existing best practices to advance the Green agenda?	0 - No Intention
		4.37	*Sustainable Development (IAM 33)*	To what extent does the organization aim to achieve Green certifications to advance the Green agenda? (e.g. LEED, PEER, EPEAT, etc.)	0 - No Intention
		4.38	*Sustainable Development (IAM 33)*	To what extent does the organization participate in industry platforms for developing new sustainability (Green ICT) best practices?	0 - No Intention

Appendix 13 – Respondent communication for participation

Email with request for participation

To: *<Respondent first name> <Respondent last name>*
From: *Edwin Elmendorp*
Date: *<date>*
Subject: Would you like to participate in my thesis research on Green ICT?

Dear Mr. / Mrs. <Respondent last name>,

In order to complete my master's degree in the field of Business Process Management and IT, I am doing research on measuring the maturity level of Green ICT in the manufacturing industry. The purpose of the project is to develop a Green ICT maturity assessment, specifically for the manufacturing industry. The outcome of such assessment can be used by an organization to determine a roadmap and strategy for improving their approach to Green ICT. Your participation is strictly confidential, and any results are completely anonymized.

For completion of this project, contribution from manufacturing companies is required. The participation consists of 4 steps that are outlined below including the estimated time required. Your total time participating will not exceed more than 3.5 hours.

1. **Information package**
   Upon your agreement to participate, I will provide an email with background information on the project, as well as the currently developed assessment and the interview questions. It is not required for you to have any prior knowledge on the topic of Green ICT.
   Timeframe <= 15 minutes

2. **Completion of the Green ICT maturity assessment**
   The next step is to complete certain sections of the assessment. The questions can all be rated on scale from 0 to 5. Your personalised email will provide information on the section I would like you to complete.
   Timeframe 45 to 60 minutes

3. **Interview to review the assessment**
   Upon completion of the assessment, an interview will be scheduled to review your experience with the assessment and discuss the validity, applicability, overall quality and other aspects. The interview is in the form of a semi-structured interview and the interview questions will be provided as part of the information package.
   Timeframe 60 to 90 minutes

4. **Confirmation of interview results**
   For validity of the research, we request to review the results of the interview and will ask for confirmation of correctness and any needed changes.
   Timeframe <= 30 minutes

The preference is to conduct the interviews between the timeframe of February 16 and March 16th, with validation of the interview the following week.
Your participation would be greatly appreciated, and I will provide a copy of the research upon completion of the project.

Thank you for your time and I look forward to your response,

Edwin Elmendorp
[redacted]

Information package for participation

To: *<Respondent first name> <Respondent last name>*
From: *Edwin Elmendorp*
Date: *<date>*
Subject: Research project information package

Dear Mr. / Mrs. <Respondent last name>,

Thank you again for helping me with this research project. As per the first email, this is the first step and contains all the information and instructions to participate. This email includes the following attachments:

1. "Green ICT for manufacturing.pdf"
   This pdf document is a presentation introducing the Green ICT, the project and its goals, and help you prepare to complete assessment, whilst providing the necessary background.

2. "Green ICT for manufacturing assessment.xls"
   This is the actual assessment in excel format. The first sheet in the excel document will provide additional instructions.
   Based on your role in the organization I would request to complete **<sections XYZ>.** Please let me know when the assessment is completed, so we can schedule the follow-up interview.

3. "Interview questions.docx"
   The third document provides the interview questions for during the interview. The interview is a semi-structured interview, which means that the questions are guiding us through a discussion. The purpose of this interview is to assess the overall validity of the assessment.

Regards,

Edwin Elmendorp
[redacted]

Appendix 14 – Interview questions

Table 29: Appendix 14, Research questions and supporting interview questions

ID	Research (Sub) Question	Interview questions
E1 – Is the presented model valid for the manufacturing industry?		
E1.1	Are the domain definitions, complete and valid for the intended purpose?	• Are the domain descriptions easy to understand to support you as a respondent for the assessment? • In your opinion, are the domains correctly covering the major elements of Green ICT for your organization? • Can you describe why the domains are correct? • If you don't agree with the selected domains, what in your opinion is missing as high-level domains, and why is this missing? • If you don't agree with the description, what in your opinion is not correct for the description (definition) of the domains?
E1.2	Are the attribute definitions, complete and valid for the intended purpose?	• Based on the provided conceptual framework presented in information package, have you had an opportunity to think about these attributes as high-level groupings? • If so – are the attributes complete? If yes, why do you believe they are complete? • If in your opinion, they are not complete, which attributes are missing and why are they missing? • Are any of the descriptions of the attributes incorrect, if so, why is this or what could be improved for this?
E1.3	Are the component definitions with the supporting questions, complete and appropriate for the intended use?	• As you completed the assessment, did you encounter components that in your opinion where not correct for this model? • All the components have a supporting question / description to help you complete the assessment, are there any questions or descriptions that were not clear enough in the model? If so, which ones and could you shortly explain what was not clear about this?
E1.4	Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?	• While performing the assessment, was the maturity scale an appropriate mechanism to rate the different components? • Where there any components where it was difficult to rate an item because the maturity scale did not fit within any of the descriptions or

ID	Research (Sub) Question	Interview questions
		came across as confusing for answering the component? If so, can you point out examples of where this was the case? • If you could make any changes to the scale, what would those be and why?
E1.5	Are there any components specifically for manufacturing missing from the model?	• Did you encounter any missing components in the model, based on your experience in this industry? • Why are they missing in your opinion?
E1.6	Are the selected respondents, the most appropriate individuals for completing the assessment?	• Based on your experience with the assessment, would you consider yourself to be the most appropriate individual? • Are there certain sections in the assessment, where a specific specialist was needed for support from your organization? If so, which sections where those and what type of specialism was required to correctly answer the question?
E1.7	Are there components that are anno 2020, not relevant or accurate for the model?	• Are the components covering new trends in the industry sufficiently in your opinion? If so, what type of trends or themes would you like to see covered? Why should these be covered? • While completing the assessment, did you find any components to be not accurate anno 2020? Why in your opinion were those not accurate?
E2 – Is the model producing results that can be used for its intended purpose?		
E2.1	Is an organization able to measure and define improvements based on the proposed model?	• After you completed the assessment, whilst reviewing the output, in your opinion does this properly reflect an organizations maturity? If so, why or why not an what could be changed to further improve this? • Based on the completed assessment, do you believe it helps the organization in defining improvements for the organization? If so, why, or why not and what should be improved to accomplish this?
E2.2	Is the developed model easy to use for the intended respondents?	• During completion of the assessment was the overall experience, easy to use and self-explanatory? If not, what would like to see improved? • Upon completion of the assessment, did the results invite you to further explore this topic and help you define improvements? If not, what should be improved in your opinion?
E2.3	Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?	• Upon completion, did the assessment provide a complete picture? If not what type of diagrams or insights would you like to see?

ID	Research (Sub) Question	Interview questions
E2.4	Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?	• Do you believe that the results of the assessment will help with the development of a strategy / roadmap for Green ICT in the organization, if not, what would be needed to accomplish that?

Appendix 15 – Respondent presentation introduction

1

2

(Fun) Facts

- The use of IT represents roughly 2% of the global CO_2 emissions. (which is about the same as the air transportation industry)
- It is estimated that through application of technology, IT has the potential of reducing emissions up to 22% globally by 2030.
- **Because of this – we would be able to decouple economic growth from our energy needs!!!**
- The US manufacturing industry represents roughly 28% of the total USA energy consumption.
- The US manufacturing industry significantly lags behind other industries in terms CR reporting and executing on the 17 United Nations sustainable development goals.

Just maybe this research contributes a little bit to the awareness and support of organizations on this topic.

3

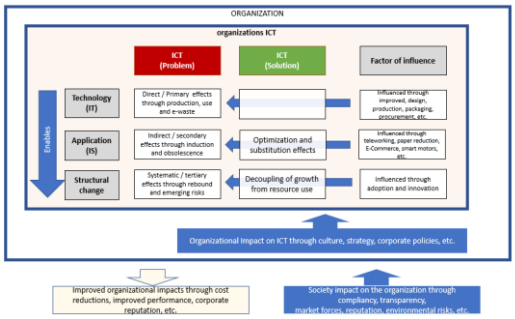
Agenda

- What is Green ICT?
- What is Green ICT for Manufacturing?
- What is ISO 55000?
- Purpose of the research?
- What do the results look like?

4

What is Green ICT

5



6

What is Green ICT

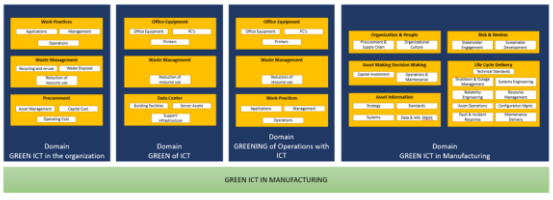
- A multidimensional construct
- Technology enables new IT applications, which in turn can cause a structural change that can have a positive effect on the environment
- These changes can also have negative effects on the environment, such as uncontrolled growth or new effects (like email spam)
- The different layers of green ICT have factors that influence to what extent green ICT is applied
- The effects of green ICT have proven to be beneficial for organizations both in monetary value and reputation

7

Green ICT Maturity for Manufacturing

8

Green ICT Framework



9

What is the model based on

- Green ICT in the organization
  - What does the ICT organization do in terms of strategy and activities to implement green practices.
- Green of ICT
  - What does the Organization do to curb and optimize the physical use of ICT technology?
- Greening of operations with ICT
  - What does the organization in general do, to optimize work practices through the lens of green (sustainability)
- Green ICT in manufacturing
  - What does the organization specifically do on the topic of manufacturing to implement green (sustainable) practices.
    - MFG domain is based on ISO 55000 developed by IAM (Institute For Asset Management), 2015

10

What is ISO 55000

11

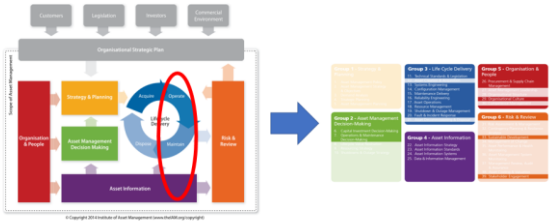
ISO 55000

- ISO 55000 describes best practices for the management of assets
- The standard is developed by IAM (Institute of Asset Management)
- IAM describes 6 major process groups, each containing multiple process areas.

- https://youtu.be/pLuMX_9WVFg
- https://theiam.org/

12

What is specific about Manufacturing (ISO 55000)



13

Purpose of the research

14

Purpose of the research

- Develop a green ICT maturity model for manufacturing.
- Validate the model through a structured interview
  - Is the model correct?
  - Is the model complete?
  - Are we missing anything from the model?
  - Etc.
- Test the model in an empirical setting
  - Empirical validation is performed with 3 participating organizations
- Improve the model based on the feedback

15

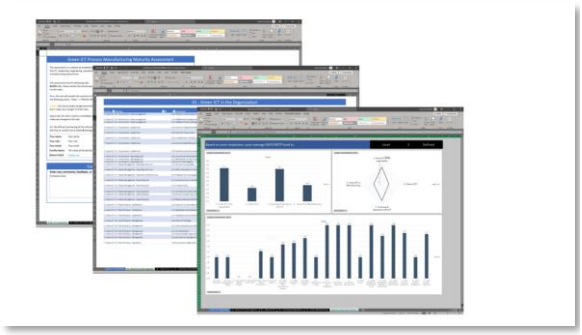
What happens to the results?

- All data will be completely anonymized!
- Respondents will have access to all anonymized data and the report.
- Respondents will receive a copy of the update maturity model.

16

What do the results look like?

17



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THANK YOU FOR YOUR HELP!

Appendix 16 – Interview results

Interview 01 - Power Utility USA – Engineering Manager

Invitation and planning

Researcher knows the respondent through his professional network. Researcher has invited the respondent personally through a short phone conversation and provided the respondent with the background information, the maturity assessment as well as the interview questions upon confirmation of participation.

Organization and respondent background

Respondent works for a regulated power utility in the South West of the united states. The utility provides power to roughly 525,000 residents and businesses. The organization has over a dozen power stations ranging from older coal stations, to solar stations, nuclear and natural gas powered. Most of the electricity is currently produced using coal and nuclear, with a desire to convert power production to more sustainable options such as solar, wind, geothermal and others of the next several decades.

The respondent is responsible for all technical and financial aspects of the power generation stations for the organization to ensure safe and reliable operations. The respondents experience spans over two decades of engineering and management experience.

Interview setting

The interview is conducted remotely via collaboration technology using Microsoft Teams. The Microsoft Teams application allows for recording both the voice interaction, video as well as the screen that is shared between the respondent and researcher. With the approval of the respondent a recording is created, and the interview has been transcribed.

Opening words

Upon the start of the interview, respondent acknowledged to have read all the information and how this assessment is a very timely topic. Respondent currently has several initiatives ongoing – for which one of the initiatives is to support the organization to become 100% renewable energy and carbon neutral. In addition, respondent is aligning its organization to the ISO55000 standard, which has been utilized for the definition of the maturity model. Respondent further describes that the regulators are currently very environmentally conscious and set the corporate agenda in terms of environmental efforts. Respondent is currently implementing policies and procedures and evaluating options to incorporate green into these procedures and policies.

Interview Questions

The respondent has provided the following answers to the research questions.

E1 – Is the presented model valid for the manufacturing industry?

- ***E1.1 - Are the domain definitions, complete and valid for the intended purpose?***
  The definition of the domains is appropriate, clear and makes sense for the purpose of the model. It did raise the question of impact. Respondent asked if there is a way of determining if a certain domain has more impact over other domains? This to support a company in making decisions on what

to focus on. Respondent reiterated the various domains and ***confirmed the domains were good***.

- ***E1.2 - Are the attribute definitions, complete and valid for the intended purpose?***
  Respondent confirmed that the attribute ***definitions were covering the correct topics***. As a first thought respondent was concerned on finding the correct individuals in an organization that can sufficiently answer the questions from an expert point of view. Respondent organization feels as very segmented and believes this to be part of a bigger issue in the industry. The span of topics is very broad, and respondent believed it would be good for many people in the organization to be part of the assessment. This would create much more awareness on what other parts of the organization are doing.

- ***E1.3 - Are the component definitions with the supporting questions, complete and appropriate for the intended use?***
  Respondent believes the assessment to be ***thorough for the purpose*** and intent of the assessment. As part of this information package, the description for the maturity rating was not included, but based on the respondent experience, this did not cause a major issue. Some topics were easy to answer, but others a little harder, because respondent is not as familiar with this topic. The questions did ***not*** feel as overly ***burdensome or repetitive***.

- ***E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?***
  The description for the maturity scale was not included, which would have been helpful, but it would not cause to change any of the answers significantly. The method to use a scale like this is appropriate versus a more elaborate method, which might be used at a later stage. For a first assessment, this is a ***good method.***

- ***E1.5 - Are there any components specifically for manufacturing missing from the model?***
  Respondent did not think any components were specifically missing from the manufacturing specific questions. It felt as ***very comprehensive***.

- ***E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?***
  Respondent believes ***the people requested to participate are the most appropriate***, however, respondent points out that the functions of IT and power generation operate in their own silo's. Even though power generation has many IT like topics – the company IT function does not see this as part of their responsibility. Secondly, respondent believes the assessment should not be limited, ***but also lower level positions should be included. The reason for this is that these individuals are often the drivers behind implementing policies*** – versus the policy makers. Perhaps the assessment needs to be tuned to their level, but it would provide a broader perspective on where the company is. Lastly – respondent believes that there is a large culture component. Culture can be shaped by policies and procedures, but it also requires leading by example to have a positive effect.

- ***E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?***
  Respondent believes the topics are ***accurate and could not think of any topics to be added or missing***.

E2 – Is the model producing results that can be used for its intended purpose?

- ***E2.1 - Is an organization able to measure and define improvements based on the proposed model?***

Respondent believes the ***outcome is appropriate*** but advised to ***tune the assessment to a specific organization to tune for terminology specifically used***. Respondent also believes it would be important to be able to perform a measurement and compare against similar companies. Then lastly, it would be good to have a better understanding how improving a specific aspect would impact any of the three components for People, Planet or Profit. The tool is ***good to start the conversations***, but ***consulting support would be needed to take the results and translate them to actual activities***.

- ***E2.2 - Is the developed model easy to use for the intended respondents?***
  Respondent believes the model is ***easy to use*** and does not necessarily overburden with questions or the complexity of the questions. The results are ***easy to interpret*** and can be used for initial conversations.

- ***E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?***
  Respondent believes the ***provided charts are a good starting point*** and could not immediately think of any specific charts to be included additionally.

- ***E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?***
  Respondent believes that the ***results can be used to define an initial roadmap***, but ***consulting support*** would be needed to define the ***impact and focus*** for such roadmap. The tool certainly raises awareness on this topic and could really help the company to understand how things are affected.

Respondent quotes

- "It's not that we don't want to do be more sustainable. But where do you start?"
- "I just don't know on certain question, and emotionally felt bad to say that we're choosing not to be green on something."

Interview 02 – Chemical Facility USA – Engineering Systems Manager

Invitation and planning

Researcher knows the respondent through his professional network. Researcher has invited the respondent personally through a short phone conversation and provided the respondent with the background information, the maturity assessment as well as the interview questions upon confirmation of participation.

Organization and respondent background

The organization is a global specialty chemicals manufacturer with manufacturing facilities in 17 different countries. The organization employs over 8,000 people globally and has a reported revenue of close to $7 USD Billion.

The respondent works at a facility in the southern part in the United States which is one of the largest facilities for the organization. The respondent is responsible for technical and financial aspects of the facility with experience spanning across three decades of working for large global chemical companies.

Interview setting

The interview is conducted remotely via collaboration technology using Microsoft Teams. The Microsoft Teams application allows for recording both the voice interaction, video as well as the screen that is shared between the respondent and researcher. With the approval of the respondent a recording is created, and the interview has been transcribed.

Opening words

Upon start of the discussion, respondent provided additional background on the topic of sustainability. The organization is owned by a large investment company. The investment company has recently requested for each of the sister companies to institutionalize a high-level position responsible for sustainability. This has brought much more focus to this topic, but it is a recent development. Respondent believes that company is on the right trajectory because of this, but a lot of work still needs to happen.

Interview Questions

The respondent has provided the following answers to the research questions.

E1 – Is the presented model valid for the manufacturing industry?

- ***E1.1 - Are the domain definitions, complete and valid for the intended purpose?***
  Respondent describes that the domains did create a bit of ***confusion***. ***The term "Operations" is typically used for "operations and maintenance" – which is the same as the fourth domain on the assessment***. Respondent recommended to create a better distinction between these elements for the names of the domains, as an example – it could be referred to as ***"facility operations"*** to create that distinction. The second comment was a question about logistics. As a specialty chemical company, there is a ***very large carbon footprint in the logistics component*** of the operation. Due to customer demand, products are being delivered through many different channels, such as trucking, trains, barges etc. Finding the optimum combination of product delivery and warehousing has been an ongoing challenge and respondent can see how a green approach could have many impacts. Respondent did highlight that his expertise was mostly on the manufacturing related questions and

the specific IT related questions are more suited for an IT function.

- ***E1.2 - Are the attribute definitions, complete and valid for the intended purpose?***
  Respondent was not paying to much attention to the attribute definitions while answering the questions. The focus was more on the question itself. During the review of the attributes together with the researcher, nothing jumped out as missing or out of order and the attributes seemed adequate for this assessment.

- ***E1.3 - Are the component definitions with the supporting questions, complete and appropriate for the intended use?***
  Respondent believes that the questions are concise, focused, well communicated. Nothing in the questions jumped out that would immediately raise many more questions. For some questions, I am just not as familiar with the topic and I could not fully answer it.

- ***E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?***
  Respondent describes that the maturity scale is easy to use. None of the questions were overly complicated or difficult to answer based on the maturity scale. What would have been helpful is ***some small examples of a typical situation for the maturity levels to help guide the respondent in answering the questions.***

- ***E1.5 - Are there any components specifically for manufacturing missing from the model?***
  Respondent explains that with the manufacturing groups, we have many conversations for optimization already. As respondent was thinking about the questions being asked, it did bring up many more detailed specific areas. For example, the optimization of specific motor types for our type of manufacturing. However, with the intent and focus of this assessment, this seemed out of scope. Respondent could not think of anything specific that was not properly covered. Respondent explained that the business would look at the ***value the green aspect will bring to the organization***. ***Any support the assessment can provide in establishing the impact of working on specific aspects will help build the case***.

- ***E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?***
  Respondent believes that from an operations point of view, it would be good to also have the assessment completed by manufacturing operations and super intendent employees. They have a very broad range of day to day activities for the facility and at least 10 to 15 years of experience and at a minimum a bachelor's degree.

- ***E1.7 - Are there components that are in 2020, not relevant or accurate for the model?***
  Respondent does not believe anything seemed old or out of date, on the contrary, some questions were much more progressive than the company currently is.

E2 – Is the model producing results that can be used for its intended purpose?

- ***E2.1 - Is an organization able to measure and define improvements based on the proposed model?***
  Respondent believes that the assessment provides usable results that properly reflect a current state of the organization. Respondent did explain that it would be important to assign the ***appropriate resources in terms of employees and time available*** if the assessment would be performed at a larger scale.

- ***E2.2 - Is the developed model easy to use for the intended respondents?***

Respondent describes that the model was easy to use and provided usable results.

- ***E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?***
  Respondent describes that it would be very important to properly define the scope of this assessment would it be performed in a real-life setting. The topic of sustainability can mean many different things for a manufacturing company and this assessment is only one small part of the whole puzzle.

- ***E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?***
  Respondent describes that the results provide a good initial insight with the different graphs, however it is also important to ***understand the impact something would have if we would improve a specific area*** of our business.

Respondent quotes

- General comment
  "Our organization has recently defined a high-level position for sustainability."
- Question E1.5
  "No questions struck me as odd or out of place, if anything some were much more progressive than I expected"

Interview 03 – Oil & Gas E&P USA – Digital Information Manager

Invitation and planning

Researcher knows the respondent through his professional network. Researcher has invited the respondent personally through a short phone conversation and provided the respondent with the background information, the maturity assessment as well as the interview questions upon confirmation of participation.

Organization and respondent background

The organization is an independent mid-size Oil & Gas company with roughly 1300 employees globally. Yearly revenue in 2019 was 1.9 billion USD and the activities consist of oil & gas exploration both onshore and offshore, as well as oil & gas production from multiple locations globally.

The respondent is the digital information manager and overseas digital information management programs. Working closely with the many different business units, he steers and advices the organization on the digital activities. Respondent has close to 20 years relevant industry experience.

Interview setting

The interview is conducted remotely via collaboration technology using Microsoft Teams. The Microsoft Teams application allows for recording both the voice interaction, video as well as the screen that is shared between the respondent and researcher. With the approval of the respondent a recording is created, and the interview has been transcribed.

Opening words

As part of the introduction, respondent describes how the company ***recently*** announced the ***appointment of the senior vice president to be the executive sponsor for ESG (Environmental, Safety, Governance) activities globally***. Respondent had read the provided materials and acknowledged that many of the topics are what the organization is starting to look at in more detail. Respondent also screened the interview questions in preparation of this discussion. Respondent further described how he ***reached out to different parts in the organization and discuss the questions*** that he did not immediately have the answer to.

Interview Questions

The respondent has provided the following answers to the research questions.

E1 – Is the presented model valid for the manufacturing industry?

- ***E1.1 - Are the domain definitions, complete and valid for the intended purpose?***
  Respondent describes how the first three domains are more applicable for his role, but also the fourth domain specifically was very applicable. Some of the questions on the fourth domain were not as closely applicable, but still very valid. The reason for this is that the organization is much more focused on oil & gas exploration, versus refining or manufacturing of chemicals. Respondent acknowledged that intent of the four different domains made good sense and was easy to follow.

- ***E1.2 - Are the attribute definitions, complete and valid for the intended purpose?***
  Respondent describes that the attributes were not something he was really paying attention to. He did not see anything as missing. This could be related to how immature the organization is on this

topic, which respondent referred to as actually ***providing awareness on attributes they are not aware off.***

- ***E1.3 - Are the component definitions with the supporting questions, complete and appropriate for the intended use?***
  Respondent believes that the questions in general served its purpose, where appropriate and clear. Some of the questions simply did not apply to our situation, so it would have been good to have the ability to indicate that in the maturity rating or some other method. The sample provided that does not apply to their organization is the question regarding smart logistics. The questions were easy to understand for the respondent and nothing came across as overly complicated or took a long time to interpreted.

- ***E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?***
  Respondent describes that the maturity scale is easy to use and enough for its purpose. The comment previously made is still valid, to perhaps label certain questions as ***not applicable for the company or business that is being assessed***. A second comment was regarding some guidance around what it means to be at level 1, level 3 etc. Sort of a go-by sheet that describes a typical outcome – to help guide a company for the level that it wants to pursue. Not directly an answer to this question but related to this is ***that senior management will want to understand what these ratings on the assessment means and what would it take to move the organization forward on specific items***.

- ***E1.5 - Are there any components specifically for manufacturing missing from the model?***
  Respondent does not believe any components are specifically missing from the model related to the manufacturing side of the business. The level and complexity are also appropriate. Respondent believes this would serve as an ***initial high-level assessment*** that then allows the organization to take it a level further for specific topics as needed.

- ***E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?***
  Respondent describes that initially the proposed individuals are good candidates, but also referred that it would be wise to ***include leadership, assign a project manager and have a central contact point that for the organization coordinates the feedback. Certain specialists from the organization will be needed to properly answer the questions.***

- ***E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?***
  Respondents feedback is that there are not necessarily components that are not accurate, but respondent proposed to focus more on the current collaboration capabilities. With current technology it is very easy to setup a quick video call, without the need to go into a special conference room***. To what level this capability is supported by an organization can have a big impact in how people collaborate more efficiently***.

E2 – Is the model producing results that can be used for its intended purpose?

- ***E2.1 - Is an organization able to measure and define improvements based on the proposed model?***
  Respondent thinks that the model can be used to define and measure improvements with support and ongoing discussion from experts. A question that needs to be asked during this process, ***what does good in green mean for a company. The ability to benchmark against others is something that will drive this discussion as well***.

- ***E2.2 - Is the developed model easy to use for the intended respondents?***
  Respondent thinks that the model can easily be used for the intended individuals.

- ***E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?***
  The model provides a good high-level picture of the organization. Before completing the assessment, respondent had some thoughts about the expected levels and the outcome feels in line with this. Respondent would like to take this assessment to the executive responsible for review and discussion.

- ***E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?***
  Respondent describes that first 2 domains would be easy to use for the definition of a roadmap. They primarily describe very IT specific elements that are for the most part directly under control. In terms of the third domain, that will likely require a bit more detail to define exact processes. For the fourth domain, specific to manufacturing, it's a very technical component that requires input from the operations and manufacturing teams and although the assessment for its purpose has the right level, actual improvements will take place a level deeper.

Respondent quotes

- Question E1.5
  "I'm not aware that we specifically do things to become greener, we do many things to enhance the performance and the outcome of that seems to be that we are also more greener, it's mostly a performance driven decision though"
- Question E2.1
  "we're always looking at benchmarking ourselves against our peers from a financial and performance production standpoint. Well, how 'bout, from a green standpoint."

Interview 04 – Chemical Facility Netherlands – Shift Manager

Invitation and planning

Researcher knows the respondent as a family member. Researcher has invited the respondent personally through a short phone conversation and provided the respondent with the background information, the maturity assessment as well as the interview questions upon confirmation of participation.

Organization and respondent background

The company is a global operating petrochemical company with 40.000 employees. Respondent works from a location in The Netherlands located in the province Limburg. This location operates several plants, some of them produce plastics that can be used to produce consumer goods, where other plants produce ethylene and propene that can be used to produce polymers.

Respondent has been with this organization for 35 years and has extensive experience in the manufacturing environment, the current role is shift manager, and in this capacity, responsible for the day to day assignment and resolution of shift and manufacturing related challenges.

Interview setting

The interview is conducted remotely via collaboration technology using Microsoft Teams. The Microsoft Teams application allows for recording both the voice interaction, video as well as the screen that is shared between the respondent and researcher. With the approval of the respondent a recording is created, and the interview has been transcribed. The language used for this interview is the Dutch language.

Opening words

Respondent prepared for the interview by completing the assessment. Respondent did not review the questions for the interview beforehand. Initial feedback from respondent was that most of the environmental savings are through the technical optimization of the facility. Respondent provided the following example, through a combination of process engineers, smart measurements, decades of practical experience and the use of an in house developed spreadsheet model has greatly reduced the daily use of natural gas with 20 to 30%. To put this in context, on a typical day, this location produces roughly 3% of the Dutch CO_2 emissions, exemplifying that ***optimizing technical parts of the facilities can have an enormous impact***.

Interview Questions

The respondent has provided the following answers to the research questions.

E1 – Is the presented model valid for the manufacturing industry?

- ***E1.1 - Are the domain definitions, complete and valid for the intended purpose?***
  Respondent describes how it would be a good addition to add a specific domain specifically for policy and strategy. The rationale is that all day to day operational decisions are ***driven by the strategy and policies that are set by management***, and management therefore needs to be involved heavily with these initiatives.

- ***E1.2 - Are the attribute definitions, complete and valid for the intended purpose?***

Respondent agrees with the attribute definitions. No attributes jumped out as missing or incorrect. As part of providing the answers respondent did not particularly pay much attention to the different attributes.

- ***E1.3 - Are the component definitions with the supporting questions, complete and appropriate for the intended use?***
  Respondent describes that the questions are easy to understand. Respondent describes that because of his role, he does not know all the answers- as he is not involved with typical IT operations, but he is very familiar with the manufacturing related questions.

  Respondent describes how ***adding small samples for the maturity scale could be beneficial, but the concern expressed is that it might take too much time*** to complete the assessment. ***A second concern is that he interpreted this as a "quick-scan"*** and based on the quick scan a more detailed assessment could be applicable.

- ***E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?***
  Respondent confirms that the scale was easy to use. An important remark was the certain aspects of the assessment where outside of what he knows about the organization. Adding an option "does not apply" to ensure that the results are not skewed could be a good addition.

- ***E1.5 - Are there any components specifically for manufacturing missing from the model?***
  Respondent describes that there are no questions regarding the topic of manufacturing wastewater. Petrochemical processes use a lot of wastewater, and optimized management of wastewater can have a big impact on the environment. In addition, optimized communication and relationship with regulatory environments could be an important topic to discuss. Thirdly – the management of change process is a topic that can have many impacts. When a plant undergoes any type of change, formal processes need to safeguard that those changes are correctly analysed to prevent accidents.

- ***E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?***
  Respondent describes that a larger group of individuals should be included in an assessment like this, from management, to procurement, production management. The assessment covers many different areas and for a realistic outcome, input from a specialist would be desired.

- ***E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?***
  Respondent does not think specific questions were old or not accurate considering the current state of technology and the type of topics currently at hand for a facility.

E2 – Is the model producing results that can be used for its intended purpose?

- ***E2.1 - Is an organization able to measure and define improvements based on the proposed model?***
  Respondent believes that current model can create awareness on this topic, but it would be difficult to define a project or approach. Manufacturing is a very technical topic, where every type of facility uses specific technology that can be optimized in different ways. To create the awareness, the model will be useful, but further steps require much more detailed analyses with manufacturing specialists.

- ***E2.2 - Is the developed model easy to use for the intended respondents?***
  The model itself is easy to use and provides an initial picture to create awareness with the provided output. Further detailing will be required to take the output and turns these into projects for

optimization.

- ***E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?***
  Respondent describes that his view is very limited with respect to the ICT components of the assessment. From a manufacturing point of view, the picture seems to be accurate

- ***E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?***
  From a manufacturing point of view, it would require more details.

Respondent quotes

- General: "One of the biggest challenges is the realization of manufacturing employees that ***plant operations has a very big impact on the environment***, we see clear differences between the shifts on how a plant is operated, which as an example has a direct results to how much natural gas is used on a daily basis, which we use about 25 metric tons per hour for a single plant."

- General: "Implementing improvements for manufacturing is in reality ***driven by cost savings and but explained to the public as green initiatives"***

- General: "Based on a conversation with a leading software manufacturer for plant optimization, the plants in The Netherlands operate much more efficient, compared to any other location in the world, mostly because of the open and direct culture and high levels of education."

- E1.5 – "Back in 2004, we already used specific software from Aspen Tech – to optimize plant operations, which greatly reduced cost."

Appendix 17 – Research questions interview results Matrix

The following respondents participated in the semi-structured interviews (see Table 30). A more detailed description is also provided in the interview results.

Table 30: Appendix 17, Overview respondents

Interview	Respondent	Organization	Location	Main area of expertise
01	Engineering Manager	1 - State regulated utility company	USA	Manufacturing
02	Engineering Systems Manager	2 - Global petrochemical organization	USA	Manufacturing
03	Digital Information Manager	3 - Midsize global Oil & Gas exploration & production	USA	IT
04	Shift Manager	4 - Global petrochemical organization	NL	Manufacturing

To corroborate the results from the interview, publicly available information is downloaded and scanned for information (see Table 31).

Table 31: Appendix 17, Published sustainability reports from respondent organizations

Interview	Organization	Sustainable report public	Clear sustainable goals / vision to curb emissions	Report conforms or aligned with
01	State regulated utility company	Yes	Yes	unknown
02	Global petrochemical organization	Yes	Yes	GRI) Standards: Core option Aligned with SDG's
03	Midsize global Oil & Gas exploration & production	Yes	unknown	SASB, GRI, MSCI ESG, TFCD, SR, ISS ESG
04	Global petrochemical organization	Yes	yes	GRI, CDP Aligned with SDG's

Table 32: Appendix 17, Research Questions results matrix

Research Question	Research sub question / topic	Interview 01	Interview 02	Interview 03	Interview 04
Generic	**Respondent location**	*USA*	*USA*	*USA*	*NL*
	Type of organization	*Power generating utility, state regulated*	*Chemical Manufacturing*	*Oil & Gas Exploration and Production*	*Chemical Manufacturing*
	Role in the organization	*Engineering manager*	*Engineering Systems Manager*	*Digital Information Manager*	*Shift Manager*
	Prepared for the interview - read the introduction and questions and completed the assessment	*Yes*	*Yes*	*Yes*	*Partially, did not read the questions*
E1 - Is the presented model valid for the manufacturing industry?	**E1.1 - Are the domain definitions, complete and valid for the intended purpose?**	*Yes*	*Confusing, rename domain 4 to facility operations*	*Very applicable, although manufacturing is relevant - but a little bit less perhaps compared to chemicals or refining for an E&P organization.*	*Yes, but separation of policy and strategy specific attributes and components would improve the model*
	E1.2 - Are the attribute definitions, complete and valid for the intended purpose?	*Yes*	*Yes, adequate for this type of assessment*	*No real attention, but nothing seemed missing*	*Yes - respondent did not pay much attention to the attributes, but are complete and valid upon review with interviewer*
	E1.3 - Are the component definitions with the supporting questions, complete and appropriate for its intended use?	*Thorough, not burdensome or repetitive*	*yes, concise, focused, well communicated*	*Yes, appropriate and clear* *Some questions did not apply. Option for maturity rating*	*Questions are easy to understand, for the questions he could answer as part of his role.*
	E1.4 - Is the maturity scale (0 to 5) easy to use and applicable for rating the components of the model?	*Yes, Good method*	*yes, not overly complicated or difficult to answer based on the scale - additional samples could help*	*yes, easy to use and enough for the purpose* *some don't apply for an E&P business*	*Scale was easy to use, but some components did not apply or outside of the respondents knowledge, having an option to indicate that would be helpful.*
	E1.5 - Are there any components specifically for manufacturing missing from the model?	*No, Very comprehensive*	*No, not for this assessment and the intent and purpose*	*no, level and complexity are appropriate*	*Several topics were raised for new or additional attention, wastewater, optimized communication with regulatory bodies and finally management of change processes.*
	E1.6 - Are the selected respondents, the most appropriate individuals for completing the assessment?	*people are most appropriate, include lower level positions for input on how things are in practice*	*Also invite manufacturing operations and super intendents to achieve practical insights*	*Yes, but important to retrieve feedback from specialists as applicable*	*Assessment covers a wide array of topics that would require input from different individuals (specialists)*
	E1.7 - Are there components that are anno 2020, not relevant or accurate for the model?	*No*	*No, some questions are more progressive than where the company currently is.*	*No components not relevant or accurate*	*The components were accurate and relevant for the organization.*
E2 – Is the model producing results that can be used for its intended purpose?	**E2.1 - Is an organization able to measure and define improvements based on the proposed model?**	*maybe, good to start conversations, specialist support needed to define actions, tune for specific organization*	*Maybe, good reflection of current state*	*Yes, with the support from experts*	*The model will create awareness on the topic, but to improve a more detailed analysis will be required.*
	E2.2 - Is the developed model easy to use for the intended respondents?	*yes, easy to use,*	*Yes, easy to use and usable results*	*Yes, easy to use for the intended individuals*	*The model itself is easy to use and provides an initial overview*
	E2.3 - Does the model provide a complete and easy to understand picture of the maturity of Green ICT within the organization?	*Charts good starting point*	*Maybe, sustainability for manufacturing company has many different points of view, proper scope is required at the start*	*Yes, provides a good high level picture, which are in line with the expected outcome.*	*From the ICT point of view, respondent is not able to answer, from a Manufacturing point of view, the presented picture is accurate.*
	E2.4 - Are the results of the model usable for developing a roadmap of activities for improving Green ICT within the organization?	*Define initial roadmap, consulting required for actual roadmap and definition of impact*	*Model provides good initial insights through different graphs*	*Yes, it depends a bit on the domain and Manufacturing domain will require additional expertise*	*To implement improvements, more details would be required from a manufacturing point of view.*

Appendix 18 – Themes analysis results matrix

Table 33: Appendix 18, Themes results matrix

Themes / Source	Interview 1	Interview 2	Interview 3	Interview 4
Invest in Green	100% Renewable Energy, state mandated, fairly recent	recent creation of high-level sustainability position Value of green for the organization?	Recent (months ago)appointment of Senior Vice President responsible for ESG (environmental, safety, governance)	Company has an active sustainability program and aligned its goals with the UN SDG's
High-level assessment	first assessment	First assessment to start discussion, more detailed topics specific to Manufacturing can be applicable	Initial assessment to then refine for more details	Initial assessment, to define a more detailed assessment
Impact of actions	Determine domain most impact How impact people, planet, profit	What is the impact for working on specific aspects?	Senior management will want to understand the impact and how to move forward.	
Green Awareness	Invite larger group to create awareness Understand how things are affected		Attributes created awareness on topics he did not know were important.	Outcome of the assessment will create awareness, which is a big challenge for the organization.
Elaborated components	Elaborate method - more questions and examples, later stage	additional samples to guide the user with the maturity scale		adding small samples to guide the user but balanced with the time to needed
Sustainable performance	We want to be more sustainable, but not sure where to start.		How to benchmark against others will drive the discussion	Driven by cost, but explained as green initiatives.
High area's of impact for manufacturing organization		Logistics High Carbon footprint	Level of adoption of good modern collaboration technology	Highest impact is improvement in the manufacturing process.
Policy, Procedures	Actively implementing green in policies			Green strategy and policy needs to be set by management
Organization specific	Tune to organization terminology		Verify applicability of the questions for the specifics of the business.	
Assessment project		Include proper resources for actual assessment More detailed scope and definition	Respondent connected with different specialists Define well organized project with PM, sponsor, central contact	
Fragmented Organization	Organization feels very segmented IT and Power generation operate in silo's			
Culture	Culture shaped by policies, but requires leading by example			

Appendix 19 – Green ICT maturity level for interviewed organizations

Organization 1 - State regulated utility company

Figure 22: Appendix 19, Organization 1 Maturity State regulated Utility

Organization 2 - Global petrochemical organization

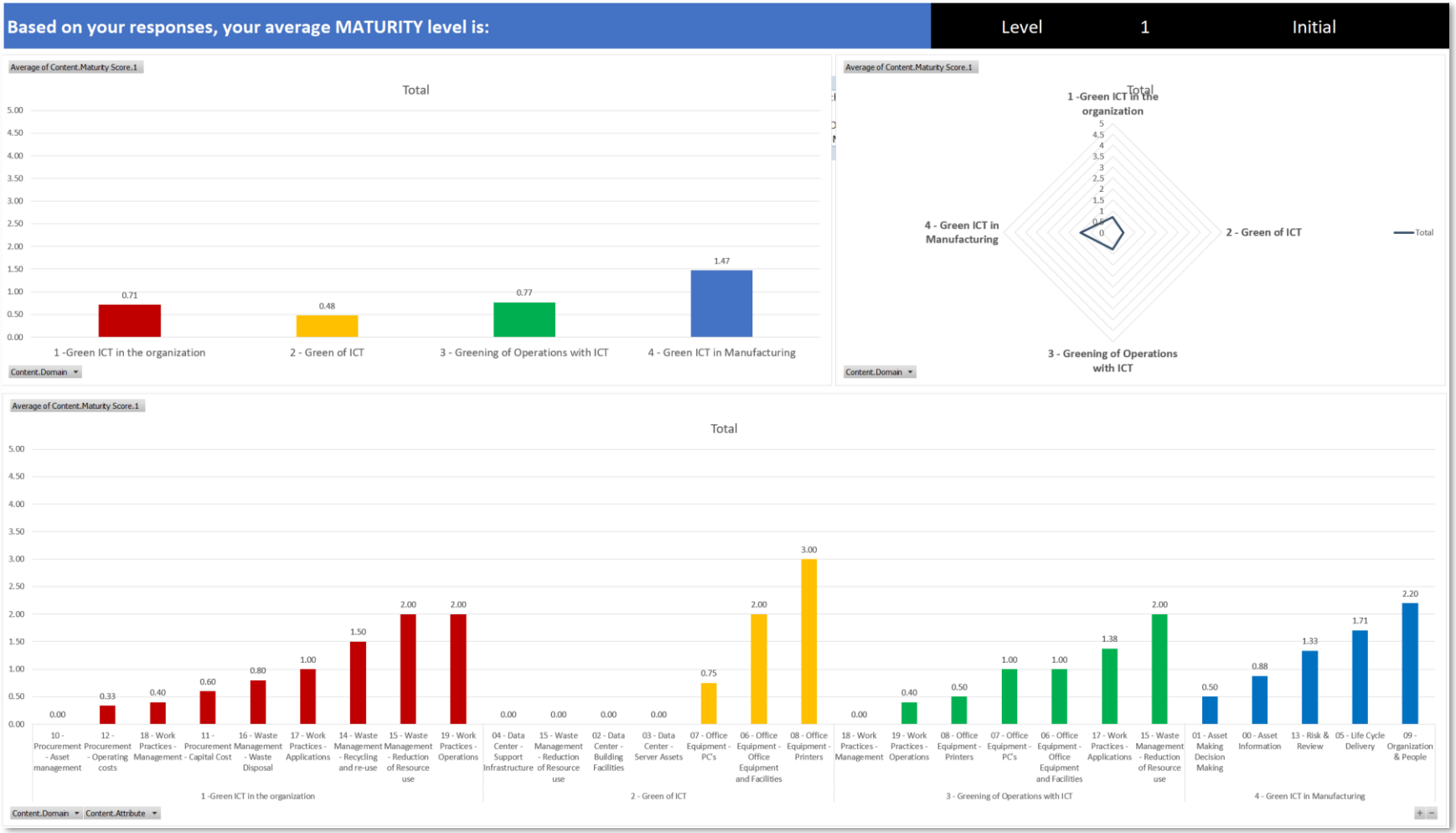

Figure 23: Appendix 19, Organization 2 Global Petrochemical Firm

Organization 3 - Midsize global Oil & Gas exploration & production

Figure 24: Appendix 19, Organization 3 Midsize global Oil & Gas exploration & production

Organization 4 - Global petrochemical organization

Figure 25: Appendix 19, Organization 4 Global petrochemical organization

Average maturity level per organization and domain

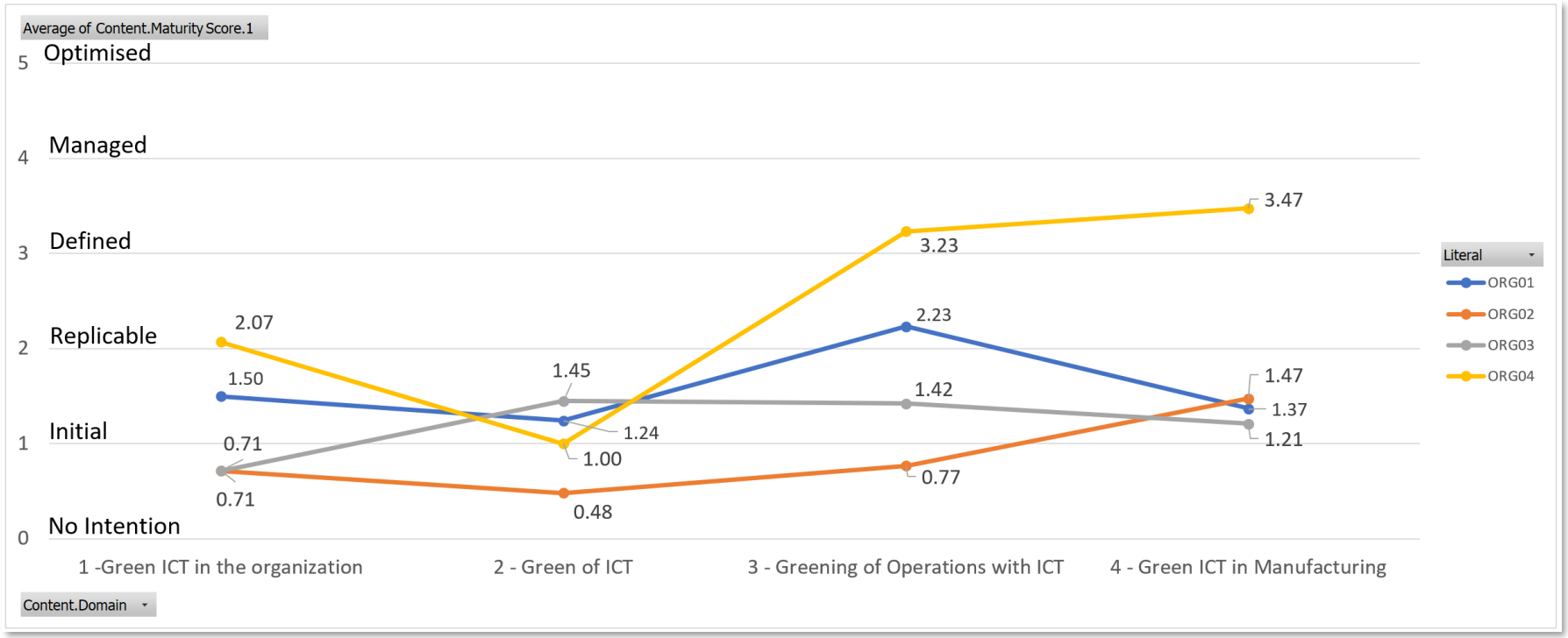

Figure 26: Appendix 19, Average Maturity Level per Organization and domain

Average results across all organizations

Figure 27: Appendix 19, Average Maturity across all Organizations

Type of impact maturity per domain for GITMM-MANU

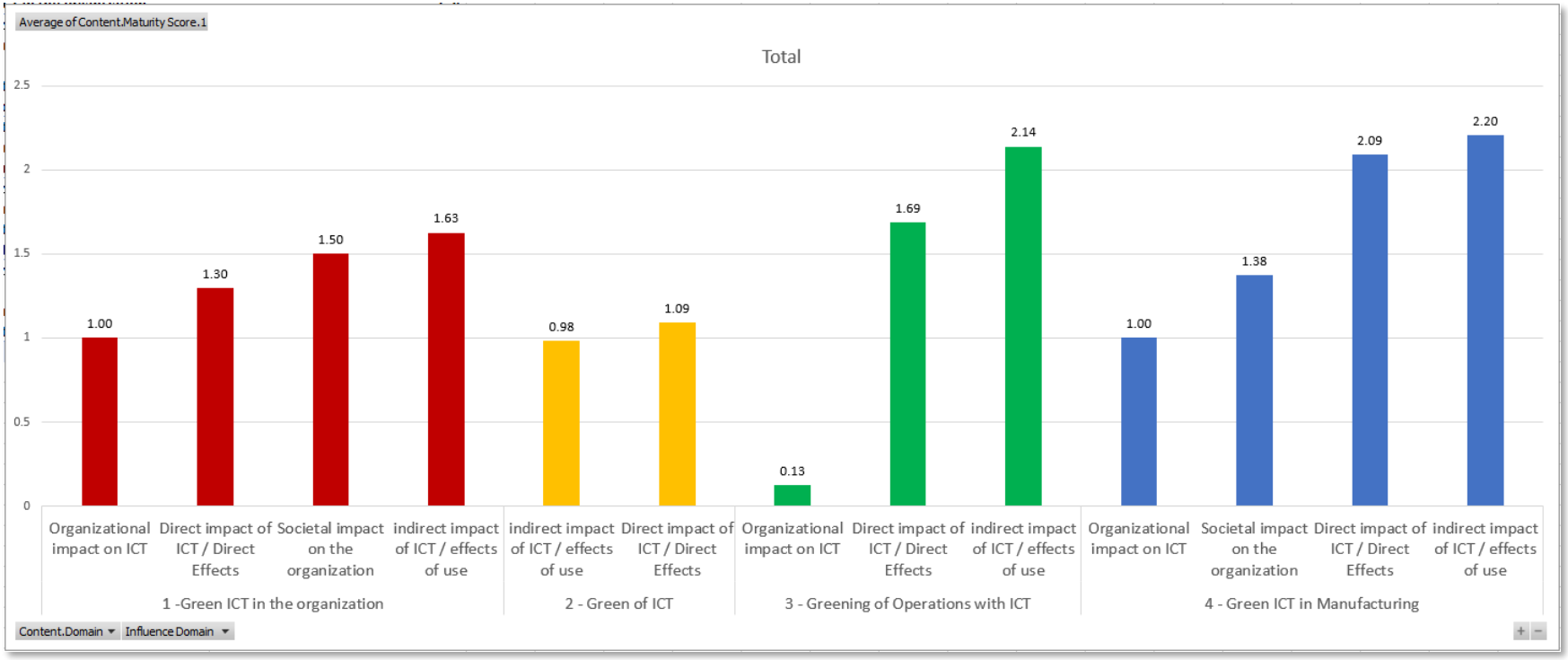

Figure 28: Appendix 19, Type of impact maturity per domain for GITMM-MANU